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PROCEEDINGS

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Part 4] May, 1935 [Volume 4

ON THE DETERMINATION OF ABSORPTION COEFFICIENTS OF SOUND FOR DIFFERENT MATERIALS

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Communicated by Dr. R. N. Ghosh

Received March 9, 1935

Abstract

Sound absorption coefficients have been obtained by the Stationary Wave Method of E. T. Paris. The source of Sound was a valve-maintained tuning fork oscillator, coupled with a single stage valve amplifier. The output of the source was carefully kept constant, and any change in it was at once detected by a Weston Galvanometer which was fed by direct current from a Copper oxide metal rectifier placed in series with the loud speaker. The "battery type" of bridge with a compensating microphone was used in finding the resistance changes. The detecting instrument in this bridge was a moving coil dead beat mirror galvanometer. The resistance changes at *minima* were observed in *terms of the deflexions* of the spot of light from the balance point; and a sensitivity much greater than those of previous workers, who used a microammeter, was obtained. The difficulty of determining low absorption coefficients with accuracy has therefore been overcome.

Absorption Coefficients at 512 frequency for some commercial absorbing materials have been obtained. Incidently some light has been thrown on the type of joints for acoustical purposes. The absorption coefficient of embossed metal plate (used in ceilings) painted with Lady Brand light blue paint has been determined, and information is gained as to why halls with such ceiling have generally good acoustical properties.

Introduction

The work described in this paper is an extension of the work already started in our Laboratory about a year ago,[1] with the object of testing the acoustic properties of different materials at normal incidence, and to study the conditions which effect changes in these properties. In the preliminary report of their investigations they had no control over certain factors, *viz.*, stability of frequency and intensity etc., which greatly affect the final value of the Absorption Coefficient of materials. These factors of uncertainty and consequent errors have been removed and controlled. In this present work the stationary wave method[2] of Paris has been followed. The following is a brief sketch of the theory.

Theory.—If a source of sound of constant frequency and intensity is placed before one end of a long cylindrical pipe, the other end of which is closed by a reflector, sound waves travel down the pipe and are reflected from the material. If the latter is a perfect reflector, such as a thick polished metal plate, there is practically no loss of energy and the amplitudes of the incident and reflected waves are the same, and stationary waves are formed in the pipe. If, however, the material absorbs part of the incident energy, the two amplitudes differ from each other, the amplitude of the reflected wave being evidently less than that of the incident wave. If it is assumed that the incident and reflected waves are plane waves, a condition which can be easily secured by adjusting the position of the source of sound before the open end of the pipe, the expression for the absorption coefficient can be obtained as was done by Paris.[2]

Let the axis of the pipe be parallel to the x-axis, and let the plane of the specimen be identical with the plane $x=0$.

Further, if the waves are supposed to be travelling in the positive direction of the x-axis, the potentials of the incident and reflected waves can be written down as

$$\varphi = A \cos k(\beta t + x) \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

$$\varphi' = B \cos k(\beta t + x + \varepsilon) \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

Equation (2) takes into account the loss of energy in reflexion. The resultant potential in the pipe is given by

$$\Phi = A \cos k(\beta t + x) + B \cos k(\beta t + x + \varepsilon) \quad \ldots \quad \ldots \quad (3)$$

Putting $t' = t + \frac{1}{2}\frac{\varepsilon}{\beta}$ and $x' = x + \frac{1}{2}\varepsilon$ we get

$$\begin{aligned}\Phi &= A \cos k(\beta t' - x') + B \cos k(\beta t' + x') \\ &= (A+B) \cos kx' \cos k\beta t' \\ &\quad + (A-B) \sin kx' \sin k\beta t' \quad \ldots \quad \ldots \quad \ldots \quad (4)\end{aligned}$$

We see from equation (4), that the motion in the pipe can be regarded as being the resultant of two superimposed stationary waves, one having an amplitude (A+B), and the other (A−B); the nodes and loops of the one being a quarter of a wavelength ahead of the other. We, therefore, find a number of positions of minimum and maximum pressure variations in the pipe, the latter being proportional to (A−B) and (A+B) respectively. The distance between a maxima and a minima is $\lambda/4$.

Now the flux of energy in the incident and reflected waves is proportional to A^2 and B^2 respectively; and by definition the coefficient of absorption (α) is given by

$$\alpha = \frac{A^2-B^2}{A^2} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (5)$$

Let the observed ratio of the maximum to the minimum amplitude be $\frac{a}{b}$. We have then

$$\frac{a}{b} = \frac{A+B}{A-B}$$

$$\therefore \alpha = \frac{A^2-B^2}{A^2} = \frac{4ab}{(a+b)^2}$$

$$= \frac{4}{2+\frac{a}{b}+\frac{b}{a}} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (6)$$

This is a very simple and elegant expression, which was first obtained by Hawley Taylor; and the whole problem of determining the absorption coefficients resolves into measuring the quantity $\frac{a}{b}$ as accurately as possible.

Description of the apparatus.—The apparatus used is essentially similar in construction and principle to the one used by Paris (*loc. cit.*). It was, however, found necessary to make some modifications in design and working in order to make it conform to the theoretical assumptions, and the essential conditions of working with the hot wire microphone as closely as possible.

Experimental Pipe and the method of mounting the specimen.—The experimental pipe consists of a long cylindrical earthenware pipe about 2 metres in length, and 12″ in internal diameter. As a single pipe of this length could not be obtained, three similar glazed drain pipes were cemented together with their axes, in a straight line. These pipes were supported on solid wooden stands which were padded to absorb any ground vibrations. One end of the pipe projects into a big wooden box

having a door which can be opened and closed easily. The crevices in the box were closed by cardboard so that the movements of the experimenter in the room did not affect the microphone inside the pipe. A moving coil loud speaker was placed inside this box, and its connecting wires were passed through narrow holes bored through the walls of the box.

The material under investigation is mounted as follows :—

A thick wooden disc of 15″ diameter and 1″ thick, having a handle on one side was first obtained. A brass plate, $\frac{1}{4}$″ thick and 15″ in diameter having holes near its edges, is then tightly screwed to the wooden disc. The specimen cut to the required shape and size is placed over this metal plate. Four circular pieces of wood having the same curvature as the plate, were placed over the specimen, and by means of long screws the latter was tightly fixed to the metal and wooden discs. A rubber washer made from an old bicycle tube was put round this whole arrangement, which was then inserted in the open end of the pipe remote from the loud speaker end. The space between the disc and the pipe was tightly packed by cotton waste in order to make it as perfectly air-tight as possible.

The measuring instrument of sound.—Hot wire microphone.

The hot wire microphones used were similar in principle and design to the "selective microphone" described by Tucker and Paris.[3] A hollow brass cylinder of about 3 cm. in diameter was put on a concentric cylinder so that one could slide over the other. The neck of the resonator was 0·2 cm. in length, and 0·8 cm. in internal diameter. The grids of these hot wire microphones were obtained from H. W. Sullivan, Ltd., London, and could carry maximum currents of 42 and 44 milliamperes. They were mounted in the necks of the Helmholtz resonators which were made in the laboratory workshop. These microphones could be tuned to 512 frequency by altering the volume of the container.

One of the two microphones used was carried at one end of a long iron rod, which passed through a hole in the sound chamber. An idea of the setting of the apparatus can be gathered from the sketch given elsewhere (Fig. 1).

As there is a change of resistance of the microphone when its axis is even slightly tilted (*vide* Tucker and Paris[3]) from its initial direction, the motion of the rod was made as smooth and easy as possible. Moreover, a thick, broad, circular wooden piece, having the same curvatures as the pipe, was transversely fixed to the rod. When the rod is moved the axis of the microphone was not altered in direction, and the unsteadiness due to tilting was greatly diminished. During the earlier parts of the work great difficulty was experienced in keeping the spot of light steady

owing to this cause, and until the motion of the rod was made quite

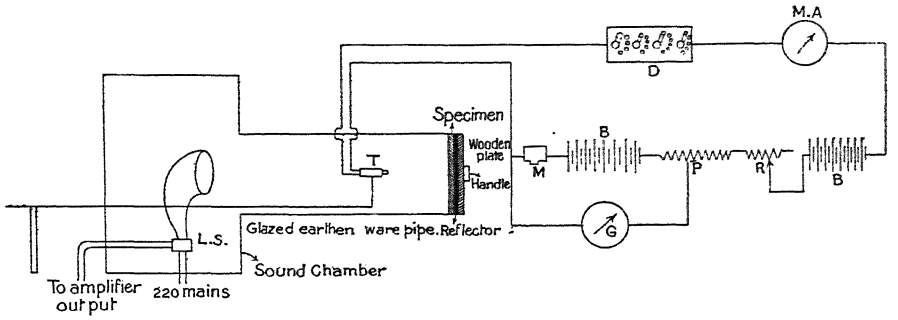


Fig. 1

M.A. Milliammeter
G. M. C. Dead beat mirror galvanometer
D. Four dial resistance box
T. Hot wire Microphone
M. Compensating microphone
B.B. Edison cells

easy it was impossible to proceed with the work.

Electrical Connexions.—Ghosh and Mohammad used the usual Post Office Box arrangement to measure the change of resistance of the grid when the source was switched on and off, and the microphone was placed in the required positions. Moreover, they did not use any compensating instrument. In order to get resistances of multiples of 0·1 ohm. they used a Callender and Griffiths Bridge in series with the balancing arm of the P. O. Box. Their heating current of the grid was 37 m.amp. which they kept constant during observations. This arrangement was at first tried. A moving coil dead beat mirror galvanometer in conjunction with a lamp and scale was used as the balancing instrument. It was found, however, that when the heating current was 37 m.amp. and the P.O. Box arrangement used, there was a very great unsteadiness in the spot of light, and the balance point shifted in a rather haphazard way. The difficulty could partly be ascribed to the heating of the resistances in the P.O. Box, and the Callender and Griffiths Bridge due to the passage of such a heavy current. But, even when thick wire laboratory made resistances were substituted for high resistances used in the P.O. Box, the unsteadiness of the balance point persisted. This proved a great source of trouble which took considerable time to be brought under control.

The behaviour of the microphone was then studied with increasing and decreasing heating currents, and it was eventually found that with heating currents of about 26 m. amp. the balance point was pretty steady, and showed no eccentricity after the current had been passed through the circuit for about three quarters of an hour. These facts can be explained as follows: During the earlier part of the passage of current, the P. O. Box

resistances get continuously heated, and their values increase, thus shifting the balance point, and virtually exhibiting that the resistance of the grid is falling. After sometime the resistances attain their steady value and no more fluctuations should arise. After this stage the unsteadiness of the balance point, when the heating current was 37 m. amp., is more difficult to explain. Probably the effect is due to the production of convection currents of air which start from one point of the grid and impinge on the other, thus producing variation in resistance of an uncertain amount. When the current is decreased, the heating is diminished, and the convection currents are also minimised.

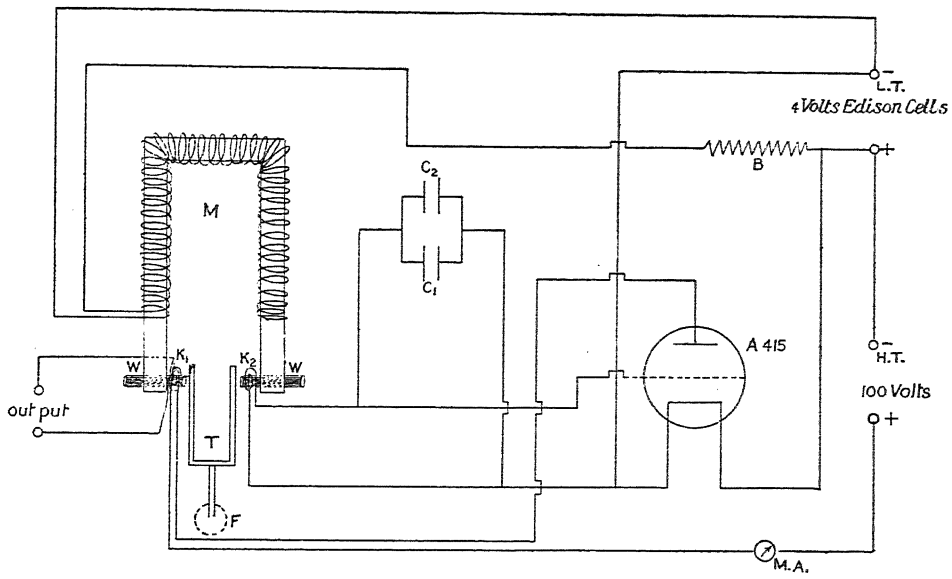
At first no compensating microphone was used in the circuit. But even when it was used the slight unsteadiness of the balance point persisted. The heating current was of course kept constant at about 26 m. amp. Edison cells of high ampere-hour capacity (150) were used as the source of current, and a series resistance of thick wire was put to adjust it.

This whole arrangement was, therefore, discarded and the "battery type" of bridge was used for measuring the change in resistance. The electrical connections of the arrangement are shown in figure 1. It is similar to the arrangement used by Paris.[2] Greater sensitivity and steadiness of balance point were certainly obtained when this type of bridge was used. The compensating microphone, which was of the same type as the one exposed to sound, but was shielded from it in a wooden box, made the balance very steady.

The grids of the microphones carried a heating current of about 26 m. amp., and had a hot resistance of about 340 ohms. When exposed to sound the fall in resistance at a maxima varied from about 13 ohms. to 28 ohms., depending upon the heating current, the output of the source, and the specimen. This fall in resistance was measured by introducing resistance in the four dial resistance box, made by H. Tinsley & Co., London, which could measure from 1000—·1 ohm. This bridge was initially balanced by the potentiometer arrangement P and a very low series resistance R shown in the figure. The rheostat position was of course kept fixed after the balance point had been obtained once.

The Source of Sound.—To obtain a source of sound which could maintain a constant output for some length of time at a fixed frequency, was a very great source of difficulty. At first a Neumann's oscillator coupled with a single stage valve amplifier, whose output was connected to a moving coil loud speaker and copper oxide rectifier, was tried. It was found, however, that the frequency of the oscillator could not be

adjusted to 512, nor could the latter be kept constant for considerable time. This arrangement was, therefore, abandoned. A valve maintained tuning fork oscillator, which was made in the laboratory, was substituted for the Neumann's oscillator. Its circuit diagram is given elsewhere (Fig. 2). The output from the oscillator was amplified by a single stage

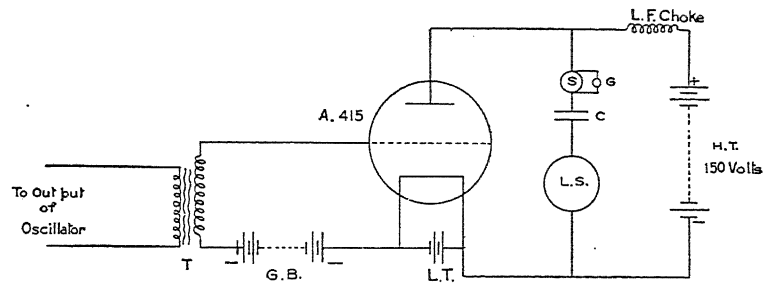


Circuit diagram of oscillator

Fig. 2

R. A Small Wire resistance
M. Electromagnet
M.A. Milliammeter
C_1 & C_2 Condensers
W. Pole pieces made of a bundle of wires
F. Base where the tuning fork was fixed
T. Tuning fork
K_1, K_2 Coils wound over wooden reels

valve amplifier (Fig. 3), as in the former arrangement. Across the output



Circuit diagram of amplifier

Fig. 3

T. Input transformer
G.B. Grid Bias battery
C. Condenser
L.S. M. C. Loud speaker
G. Weston galvanometer
S. Copper oxide Metal Rectifier

of the amplifier a capacity, a loud speaker and a copper oxide rectifier, to which a Weston D.C. galvanometer was connected in parallel, were placed. The rectifier fed direct current in the galvanometer, whose deflexions thus indicated the output of the loud speaker. This arrangement was very sensitive, and even a slight change in the output could be at once observed. A milliammeter in the plate circuit of the oscillator valve showed the constancy of the oscillator output. The only factor over which I had no control for keeping the output of the source constant, was the 220 mains which was used in exciting the electromagnet of the moving coil loud speaker. However, by working at suitable times when the load on the mains was not excessive, the exciting voltage could be kept fairly constant. The stability in the construction of the oscillator, and the constancy of the voltages of the batteries used in supplying the high and low tensions to the oscillator and amplifier kept the output of the source constant.

Method of observation.—As has been mentioned before it was our purpose to find $\frac{a}{b}$ as accurately as possible, and the following method was employed.

The microphone was at first tuned to the note given out by the loud speaker by altering the volume of the container, and making the deflexions at a minima as large as possible.

The next step was to fix up the position of the loud speaker before the open end of the pipe in order to produce stationary waves. With a certain position of the loud speaker, the deflexions at various positions of the microphone inside the pipe were noted; and a graph of the relative positions of the microphone and the deflexions plotted. The loud speaker was shifted backwards and forwards till this graph was a smooth curve of the type shown in figure 4. During both these experiments the brass plate reflector was placed at the end of the pipe opposite to the loud speaker end.

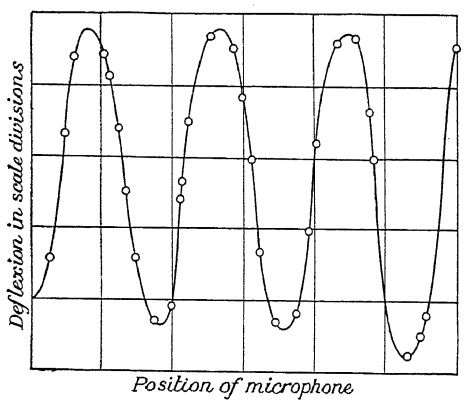


Fig. 4

The deflexion obtained, when the microphone was placed at a minima after being properly tuned, was as large as 8 to 10 cms. This deflexion

corresponds to the resistance change at the minima. A deflexion of this order is much greater than that obtained by others[4] who have used a microammeter for guiding the change in resistance at a minima. A galvanometer of the type I have used is certainly a more sensitive instrument than the microammeter, which is, however, much less troublesome to work with. The percentage of error in determining a/b is, therefore, very much minimised. Moreover, the use of a galvanometer makes the apparatus susceptible to the measurement of very small absorption coefficients.

The specimen under test was mounted in its place as explained in the earlier pages, and the bridge was balanced by shifting the pointer P. (For convenience and ease in working, a number of switches for turning the various low and high tension batteries on and off, were fixed up in the working table in front of the experimenter). The source of sound was turned on, and the microphone moved by the slider till the position of minimum deflexion near the specimen was obtained. The resistance change, ρ_1, in terms of the galvanometer deflexion was noted. The microphone was then moved, away from the specimen, and the resistance change, ρ_2, at the maxima determined. This was done by slowly introducing resistance in the dial resistance box D, and obtaining the balance point. This procedure had to be adopted as the deflexion at a maxima was so great that the spot of light was completely absent from the scale. To determine the exact position of a maxima the rod was slowly moved while the resistance introduced in D nearly corresponded to the resistance change at maxima. When the maximum deflexion on the scale was obtained in this state, the balance was obtained and the resistance change noted. A few trial experiments very much simplified further observations. Besides the use of a variable resistance of 1 megohm in series with the galvanometer was a great source of convenience in obtaining the balance point at a maxima. Let these two resistance changes be ρ_1 and ρ_2 respectively.

The specimen was now removed, and the perfect reflector, (which was simply a brass plate of $\frac{1}{4}''$ thickness) was mounted in its place. The bridge was again balanced, and the position of the node nearest the reflector was found by sliding the microphone in the pipe. In this position there should be no deflexion of the spot if the reflexion is perfect; since, however, it is never the case, a deflexion of a few millimeters always occurs, which is neglected without appreciable loss in accuracy. The microphone was then displaced, first on one side and then on the other of this minimum position till a deflexion corresponding to the resistance change ρ_1 was obtained in

each case. Both these positions were noted on the horizontal cathotometer scale. Let the distance between them be denoted by $2Y_1$. The position of the node was also noted on a scale placed horizontally along the bar.

The microphone was then displaced, away from the specimen; but before doing so a resistance equal to ρ_2 was introduced in the resistance box D, and by slowly decreasing the variable resistance in series with the galvanometer a balance point was obtained for a certain position of the microphone. This position was noted on the scale. Let the distance through which the microphone has been moved from minima to this point be called Y_2.

Now since in a stationary wave, the pressure amplitude at a point is proportional to sin KY, where Y is the distance from the node to the point,

OBSERVA

Material	Heating current of the grids in milli-amps.	Specimen in position.			Reflecting plate in position. Scale readings on a cathetometer for resistance change ρ_1 taken on both sides of the minima.		
		Res. change ρ_1 at 1st minima in scale divisions.	Intensity of source in scale divisions of galvanometer.	Res. change ρ_2 at maxima in ohms.	A	B	$2Y_1$ in cms.
1. Felt $\frac{1}{2}$" thick.	26 (approx.)	79	18	27·4			
		78	18	27·2	3·145 cms.	1·490 cms.	1·655
		78	18	27·2	3·150 „	1·480 „	1·670
		77	18	27·2	2·810 „	1·135 „	1·675
		79	18	27·2	2·805 „	1·130 „	1·675
		78	18	27·2			
2. Acoustic asbestos $\frac{1}{4}$" thick obtained by courtesy of Bird & Co., Cawnpore.	26 (approx.)	21	18	28·6	2·825 cms.	2·005 cms.	0·820
		23	18	28·6	2·870 „	2·050 „	0·820
		22	18	28·6	2·890 „	2·100 „	0·790
		20	18	28·5	2·905 „	2·100 „	0·805
		20	18	28·6			
		20	18	28·7			

and $K = \frac{2\pi}{\lambda}$; the pressure amplitudes which produce resistance changes of ρ_1 and ρ_2 must be proportional to sin KY_1, and sin KY_2 respectively. We have, therefore

$$\frac{a}{b} = \frac{\text{the pressure amplitude at maxima}}{\text{the pressure amplitude at minima}} = \frac{\sin KY_2}{\sin KY_1}$$

$$\text{and } \therefore \alpha = \frac{4}{2 + \frac{a}{b} + \frac{b}{a}} = \frac{4}{2 + \frac{\sin KY_2}{\sin KY_1} + \frac{\sin KY_1}{\sin KY_2}}$$

The value of K was found by noting the distance through which the microphone had to be shifted from one minima to another, and dividing π by this distance. Knowing Y_1 and Y_2 the value of α was calculated.

TIONS

Mean $2Y_1$ in cms.	Length of the rod moved from minima to the position where the resistance change was ρ_2.	Mean Y_2 in cms.	$\lambda/2$ from one minima to another in cms.	Mean $\lambda/2$ in cms.	KY_1	KY_2	α at 512 frequency.	Date of observations.
1·669	13·58 cms. 13·48 „ 13·57 „ 13·52 „	13·538	33·9 cms. 33·9 „ 33·9 „	33·9	4°, 26′	71°, 54′	0·278	27th December, 1934.
0·8088	20·15 cms. 20·45 „ 20·45 „ 20·15 „	20·30 cms.	33·85 cms. 33·90 „ 33·85 „ 33·80 „ 33·90 „	33·86	2°, 9′	72°, 6′	0·146	30th December, 1934.

OBSERVA

Material.	Heating current of the grids in milli-amps.	Specimen in position.			Reflecting plate in position. Scale readings on a cathetometer for resistance change ρ_1 taken on both sides of the minima.		
		Res. change ρ_1 at 1st. minima in scale divisions.	Intensity of source in scale divisions of galvanometer.	Res. change ρ_2 at maxima in ohms.	A	B	$2Y_1$ in cms.
3. 'Treetax' $\frac{1}{2}$" thick obtained by courtesy of Heatley Gresham, Ltd., Calcutta.	23 m. Amp. (approx.)	105 104 104 104 103 104	20·5 20·5 20·5 20·5 20·5 20·5	14·4 14·3 14·4 14·4 14·5 14·4	3·800 cms. 3·635 „ 3·535 „ 3·620 „	0·810 cms. 0·705 „ 0·665 „ 0·725 „	2·990 2·930 2·870 2·895
4. Embossed metal plate (obtained by courtesy of Winter Bros., Calcutta) painted with two coats of Lady Brand Light Blue paint.	23 (approx.)	18 19 18 18 18 17	20·5 20·5 20·5 20·5 20·5 20·5	13·5 13·5 13·6 13·5 13·6 13·5	2·790 cms. 2·695 „ 2·735 „ 2·845 „	1·595 cms. 1·565 „ 1·575 „ 1·615 „	1·195 1·130 1·160 1·230
5. Felt $\frac{1}{2}$" thick same as No. 1. Re-investigated to verify the other values.	25 (approx.)	27 26 26 26 26 26	20·5 20·5 20·5 20·5 20·5 20·5	17·1 17·1 17·0 17·3 17·1 17·2	2·685 cms. 2·740 „ 2·730 „ 2·700 „	1·410 cm. 1·390 „ 1·405 „ 1·405 „	1·275 1·350 1·325 1·295
6. Red cloth, known in Hindustani as "Tool". It was mounted at a distance of about one and a half cm. from the reflecting plate.	25 (approx.)	10 11 10	20·5 20·5 20·5	17·7 18·3 18·0	1·535 cm. 1·725 „ 1·645 „	0·75 cm. 0·805 „ 0·800 „	0·785 0·920 0·845

TIONS

Mean $2Y_1$ in cms.	Length of the rod moved from minima to the position where the resistance change was ρ_2.	Mean Y_2 in cms.	$\lambda/2$ from one minima to another in cms.	Mean $\lambda/2$ in cms.	KY_1.	KY_2.	α at 512 frequency.	Date of observations.
2·921	24·1 cms. 24·0 „ 24·0 „ 24·0 „	24·025 cms.	34·2 cms. 34·0 „ 34·1 „ 34·1 „ 34·2 „	34·12	7°, 42′	53°, 12′	0·491	16th February, 1935.
1·179	25·15 25·00 25·15 25·20	25·125	34·2 34·0 34·1 34·0 34·0	34·06	3°,7′	47°, 12′	0·257	17th February, 1935.
1·311	25·0 24·8 24·8 24·8	24·8	34·2 34·2 34·2 34·2	34·2	3°,27′	49°, 30′	0·272	19th February, 1935.
0·850	23·3 23·0 23·4	23·23	34·2 34·1 34·2	34·16	2°, 14′	57°, 36′	0·169	2nd March, 1935.

Discussion

This method of finding the absorption coefficients is indeed a very simple, efficient and quick one. The drawback of measuring absorption coefficients of materials having a low value, with accuracy, has been partly overcome by using a moving coil galvanometer with the battery type of bridge and a compensating microphone. This whole arrangement is certainly many times more sensitive than those of previous workers, as can be seen by comparing the deflexions and corresponding resistance changes at minima. With a heating current of 28 m. amp., Paris[2] obtained a deflexion of 2·5 divs. of the microammeter scale at minima for a material having an absorption coefficient of ·26; while Ghosh and Mohammad[1] with a heating current of 37 m. amp., obtained a deflexion of 17 mm. on a scale for a material having an absorption coefficient of ·25. In my case, with a heating current of about 26 m. amp., a deflexion as large as 80 mm. is obtained, on a scale placed a metre away from the galvanometer, for a material having nearly the same value of absorption coefficient, namely ·27. The use of the 'battery type' of bridge instead of the ordinary P. O. Box arrangement, made the conditions of working very steady.

In the apparatus used by others there was no arrangement for keeping the frequency and output of the source constant. These two sources of error were eliminated to a great extent in these experiments.

Although no such elaborate arrangement for minimising the effects of the ground vibrations on the microphone inside the pipe, as mentioned by Paris, was made, yet by working during the holidays at quiet hours, his conditions of working could be approximated to very closely, the more so, because the main roads round the laboratory are quite far away, and there is never such a heavy traffic as those of trams etc. on them.

In the case of 'Treetex', four pieces were joined together so as to form a circle, and there was a space of about 2 mm. at each joint. This is most probably the reason why its absorption coefficient is so high. Incidently it throws some light on the value of joints for acoustical purposes.

The most interesting material investigated was an embossed metal plate, obtained by courtesy from Winter Brothers, Calcutta. (These plates painted with various colours, are extensively used in the ceilings of halls and auditoriums.) This plate was given two thick coatings of Lady Brand light blue paint, and dried. The high value of absorption

coefficient, *e.g.*, ·25 shows why such halls have generally good acoustical properties provided other factors are also taken into account.

Lastly, the fact that almost the same values of absorption coefficients are obtained at different times, and with entirely different conditions of working with the apparatus, places the accuracy of these values beyond doubt.

In the end I offer my most sincere thanks to Professor M. N. Saha for his kind interest and encouragement, and to Dr. R. N. Ghosh for his help and guidance throughout the work.

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ON THE DIRECT FORMATION OF BROMIDES AND THE DISTANCE OF THE CLOSEST APPROACH OF ATOMS OF BROMINE

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Communicated by Prof. M. N. Saha

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In two previous communications[1, 2] it has been shown by the author that the distances of the closest approach of atoms of metals determine their capacity to react with water. It has been shown there that metals whose distances of the closest approach of atoms are above 3·00Å can react with water. In subsequent communications[3, 4] the author has pointed out that in the capacity for the formation of amalgams also, the distances of the closest approach of atoms of the metals play a prominent rôle and metals having not less than 2·5Å as their values for their closest approach of atoms can form amalgams with mercury, which latter has been shown to have 2·5Å as the value of the distance of the closest approach of its atoms. The object of the present communication is to show that the reactivity of elements with bromine also depends upon the distances of the closest approach of atoms of the elements concerned and to arrive at a probable value for the closest approach of atoms in the case of bromine. Further the value so obtained is in accord with that calculated according to the formul aproposed by the author (*loc. cit.*).

Bromine is known to react directly with a large number of elements. The following are the cases recorded in literature. The values* for the distances of the closest approach of atoms of the elements are given within brackets:

Copper (2·54), Gold (2·88), Potassium (4·50), Zinc (2·67), Mercury[4] (2·50), Aluminium (2·86), Tin (2·80), Cobolt (2·514), Iron (2·54), Bismuth (3·47), Molybdenum (2·72), Zirconium (3·18), Calcium (3·93), Magnesium (3·22), Germanium (2·43), Lead (3·48), Indium (3·24), Cerium (3·64), Sulphur (——), Tellurium (——), Chromium (2·508), Antimony (3·37), Thorium (3·54),

* The values for the distances of closest approach of atoms are taken from Bragg and Bragg's *X-ray and Crystal Structure*, Fifth Edition, p. 163.

Silicon (2·35), Sodium (3·72), Tantalum (2·833), Beryllium (——), Rubidium[2] (4·56), Caesium[2] (5·7), Lithium (3·03), Cadmium (2·96), Phosphorus (——), Arsenic (——), Thallium (——), Silver (2·876), Rhodium (2·70), Nickel (2·505), Vanadium (2·64), Titanium (2·96), Selenium (——), Strontium (——).

It will be evident from the above table, that in the case of elements which directly unite with bromine, the distances of the closest approach of their atoms seem to be greater than an approximate figure 2Å. It has been shown previously (*loc. cit.*) that mercury has 2·5 Å as its distance of the closest approach of its atoms as those metals which have atomic approach values greater than 2·5 Å can only react with mercury to form amalgams. Arguing in the same manner we are led to the conclusion that the closest atomic approach value of bromine should in all probability approximate to 2 Å, as the elements having closest atomic approach values greater than the approximate value 2 Å can react with it directly and any element having atomic approach value lower than this approximate figure, for instance, carbon having atomic approach value* 1·54 Å or 1·50 A, has not been found to react with it.

This is further corroborated by the fact that the value for the distance of the closest approach of atoms of bromine as calculated from the author's[4] formula $D = \frac{P}{Vi \times d^{k/v}}$ is 1·73 Å (approximating to 2 Å) which is intermediate between that of silicon, *viz.*, 2·35 with which it react directly and that of carbon, *viz.*, 1·54 or 1·50 with which it does not react.

Much like the rule of the reactivity of metals with water (*loc. cit.*) and that of the formation of the amalgams with mercury (*loc. cit.*) a rule may hence be laid down in the capacity of elements to react directly with bromine that elements with the distances of the closest approach of their atoms above 1·73 Å can only react with bromine. It would thus seem probable that strontium, phosphorus and other elements incorporated in the table, which are known to react directly with bromine, but data for the closest atomic approach values of which seem to be wanting, have values for their closest approach of atoms which are greater than 1·73 Å.

It may be noted also that there seem to be a few exceptions to this rule, *viz.*, platinum, osmium, iridium, ruthenium and palladium which according to the above rule should directly form bromide but no distinctive evidences seem to have been recorded on their direct formation.

* Bragg's *X-ray and Crystal Structure*, Fifth Edition, p. 163.

Calculation of the value for the closest approach of atoms of Bromine.

The author proposed a formula (*loc. cit.*) for the calculation of the distances of the closest approach of atoms of elements according to which

$$D = \frac{P}{Vi \times d^{k/v}}$$

where D is the distance of the closest approach of atoms, P the parachor, Vi the ionisation potential, d the atomic diameter of the element in question and k, a constant having the value 1·58, and v is the valency.

For Bromine,

Parachor = 68·0 (Sugden's *Parachor & Valency*, p. 181)

Ionisation potential = 10·0 (Hughes & Dixon, *Phys. Rev.* (2), **10**, 495, 1917)

Atomic Diameter = 2·38 (Bragg, *Phil. Mag.* (6) **40**, 169, 1920)

Valency = 1

It will be seen on calculation with the help of the formula, the distance D of the closest approach of atoms of bromine is 1·73 Å which is intermediate between the value of carbon on the one hand and the silicon on the other.

We are therefore led to the conclusions:

(1) Bromine has its closest atomic approach value 1·73 Å.

(2) Elements having their values for the distances of the closest approach of atoms above 1·73 Å are only capable of reacting with bromine.

Further elucidation of the problem will be taken up later.

My thanks are due to Prof. P. Neogi and Prof. A. Maitra for their kind interest in the work.

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PHOTOREACTION IN TROPICAL SUNLIGHT

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The subject of photoreaction of organic compounds is one which has attracted the attention of chemists for a long time. A classical case in this respect is perhaps that of chloroform which was shown by Victor Meyer to undergo decomposition in presence of moisture, air and sunlight into carbonyl chloride and hydrochloric acid. The coloration of phenol in presence of air and light was noticed by Gibbs,[1] and De Vres[2] found that aqueous solutions of oxalic, malic and tartaric acids underwent complete decomposition in sunlight if access of air was allowed. Photo-oxidation of polyhydric alcohols has been carried out by De Coninck[3] and Berthelot,[4] that of *p*-phenylenediamine by Baudrowski,[5] of benzaldehyde-phenylhydrazone by Chattaway,[6] of organic dyestuffs of every description by Barat and Dutt.[7] Photo-reduction of ketones to pinacols was studied by Boeseken and Coehn[8] and conversion of benzophenone into benzpinacone by Gimco.[9] Photo-polymerisation of *p*-vinylanisole was noticed by Toepfer,[10] and of cinnamic acid and unsaturated compounds, in general by Ciamician and Silber.[11] In the same way, photo-isomerisation of coumarinic acids and their esters was noticed by Perkin,[12] of substituted ethylenes by Stoermer[13] and of esters of substituted acrylic acids by Rice.[14] From the work of the above authors who are only a few out of the large number that has worked in this field, it is quite evident that sunlight in presence of air very often brings about most profound decompositions of organic substances the nature of which is very often obscure. Sunlight therefore can easily be regarded as one of the most powerful agents for bringing about the decomposition of organic compounds and the present investigation was undertaken in order to illucidate the nature of at least some of the decompositions from a scientific point of view. The following types of compounds were selected for the purpose of examination: aromatic amines, mono-and poly-hydric phenols, diamines, aminophenols and their derivatives,

amino-acids, aldehydes, dyestuffs, aliphatic hydroxy acids, unsaturated acids, heterocyclic compounds, aromatic oximes, phenylhydrazine and sulpho-carbamide. The details of the procedure adpoted as well as the results obtained are given in the experimental portion of the paper.

Experimental

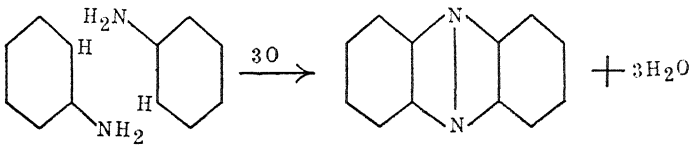
The substances used in connection with the experiments described in this paper were submitted to an exhaustive process of purification, until they were obtained in a state of almost ideal purity. For this purpose repeated distillations under ordinary and diminished pressures, fractional crystallisations from various solvents, sublimations and distillations in steam were resorted to. The pure substances thus obtained were immediately utilised in experiments on photoreaction without storage. For this purpose perfectly clear Jena glass conical flasks of about one litre capacity were filled almost to the neck with solutions of the above-mentioned purified substances in either water, dilute hydrochloric acid, dilute caustic soda or alcohol and after covering the mouths of the flasks with pieces of glazed paper tied loosely so as to allow free access of air, the flasks were fixed in position on a specially erected platform on the high roof of the laboratory where they could get direct sunshine from morning till evening. In this position the flasks were not disturbed save for occasional replenishment of solvent evaporated. They were only removed for examination when profound changes as shown by the formation of large quantities of precipitates, formation of intense colorations, copious evolutions of gases etc. had taken place. The strength of the solution employed in most of the cases was 2 per cent.

Aniline

A 2% solution of this substance in N/5 hydrochloric acid was perfectly colourless in the beginning, but in course of only one day the colour changed to pinkish brown and in two days' time yellow precipitates began to come down. In course of seven days the colour of the solution had changed to deep pink and the quantity of the precipitate went on increasing. At the end of the 26th day the colour of the solution was crimson and on the 42nd day it had changed to vermilion red, the quantity of the precipitate increasing all the time. The precipitates were filtered off from time to time. At the end of the 135th day no further precipitation was observed and the experiment was discontinued.

The precipitate which had a brownish yellow colour was crystallised from alcohol and finally sublimed in glistening yellow needles

melting at 170°. It gave an intense violet coloration with concentrated sulphuric acid and had all the properties of phenazine. It was definitely identified to be *phenazine* by a direct comparison with the known substance. The substance must have been formed from aniline in accordance with the following scheme :



The following aromatic amines were then exposed to sunlight in a manner similar to aniline: *Ortho-*, *meta-* and *para-*toluidine, 1 : 3 : 4-xylidene, dimethylaniline, *alpha-* and *beta-*naphthylamine, benzidine, *ortho-*nitraniline and nitroso-dimethylaniline. The results are given below:—

Ortho-toluidine—gave *1 : 5-dimethyphenazine* and after 120 days no further precipitation occurred. Violet-black microscopic crystals subliming to golden yellow needles melting at 160°. (Found N=12·9%).

Meta-toluidine– gave *2 : 6-dimethyphenazine*, and precipitation ceased after 71 days. Violet crystals subliming to glistening orange-yellow needles melting at 156°. Like the compounds mentioned above, it also gave intense violet colour with concentrated sulphuric acid. (Found N=13·2%).

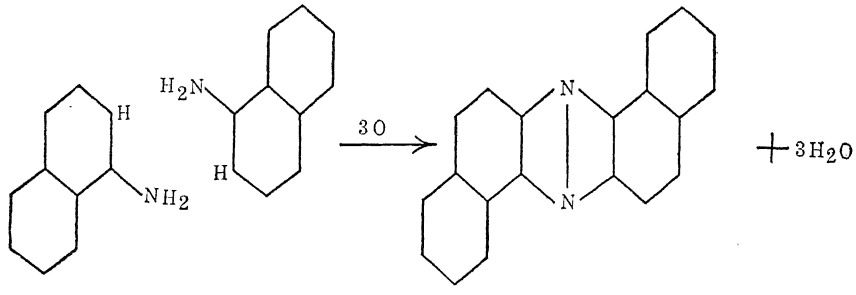
Para-toluidine—gave complete precipitation after 123 days' exposure. The dark brown precipitate sublimes in golden yellow needles which decompose without melting on heating. It gave an intense brown-violet colour with concentrated sulphuric acid and was in all probability *3 : 7-dimethyphenazine* although this could not be confirmed for want of authoritative data. (Found N=13·7; $C_{14}H_{12}N_2$ requires N=13·4%).

Dimethylaniline—did not show any perceptible change even after exposure for 141 days and is indeed one of the most stable of organic substances that have yet been examined.

1 : 3:4-xylidene—gave only a trace of a precipitate after 121 days' exposure and is also a very stable substance. The quantity of the precipitate was too insufficient for chemical examination.

Alpha-naphthylamine—gave large quantities of precipitate and after 107 days' exposure the precipitation was almost complete. Dark brown powder subliming on careful heating to reddish brown glistening needles which decompose when heated in a sealed tube without melting. The

substance is undoubtedly αβ-*dinaphthazine* formed in accordance with the following scheme:



(Found N=9·8 %)

Beta-naphthylamine—gave a dark brown precipitate and after 110 days, the precipitation was almost complete. Dark brown crystalline powder subliming in glistening orange-brown needles on careful heating. M.P. 240°. The substance is undoubtedly ββ -*dinaphthazine* formed similarly to the above. (Found N=9·6; $C_{20}H_{12}N_2$ requires N=10·0%)

Benzidine—gave a dark coloured precipitate which practically ceased to form after 94 days' exposure. The substance sublimed on careful heating in chocolate-brown glistening needles which did not melt up to 300°. It gave an indigo blue coloration with concentrated sulphuric acid and was undoubtedly a phenazine derivative, but it could not be definitely identified for want of confirmatory data.

O-nitraniline—this substance remained absolutely unchanged even after 125 days' exposure and is undoubtedly one of the stablest of organic compounds known.

p-Nitrosodimethylaniline—gave complete precipitation after 42 days' exposure. The precipitate which was a yellow crystalline substance, on recrystallisation from alcohol melted at 220° and was found to be identical with *p-nitrosodimethylaniline*.

p-Nitrosodimethylaniline in hydrochloric acid solution instead of water as given above, gave a dark brown precipitate which went on accumulating slowly even after 111 days' exposure. It did not melt even at 300° and dissolved in concentrated sulphuric acid with a brown colour and in caustic alkalies with a blackish-brown colour. The substance could not be identified.

Mono-and poly-hydric phenols

Phenol—in aqueous as well as in alkaline solution on exposure to sunlight at first turned dark red (2 days), then the colour changed to

yellowish brown (6 days) and lastly a brown precipitate began to collect (13 days). This was removed after 64 days' exposure. It crystallises from alcohol in dark brown needles which shrink at 160° but does not melt up to 300°. It dissolves in concentrated sulphuric acid with a dark brown colour and does not give any colour reaction with ferric chloride. It is also insoluble in dilute caustic alkalies. The substance could not be identified.

Quinol—gave a small quantity of a black precipitate after 121 days' exposure which had properties somewhat similar to the above. This also could not be identified. On distillation with zinc dust an odour of diphenyl was noticeable.

Resorcinol, *Catechol* and *Pyrogallol*—remained practically unchanged even after exposure for 156 days, and are undoubtedly some of the stablest of organic substances.

α-*naphthol*—in caustic soda solution gave a black precipitate which was collected after 78 days' exposure. This does not melt or sublime and is insoluble in all organic solvents as well as in caustic soda. In concentrated sulphuric acid it dissolves partly with a violet-black colour. It could not be identified.

β-*naphthol* in caustic soda solution gave a precipitate with properties similar to the above after 80 days. It also could not be identified.

Aromatic diamines

O-phenylenediamine—in one per cent solution in dilute hydrochloric acid began to deposit glistening violet crystals after only 2 days' exposure, and the solution became dark red in colour. The precipitation was complete after 125 days. On careful examination the precipitate was found to be identical with the *hydrochloride of 2 : 3-diaminophenazine* already prepared and described by Salkowski [15], Otto Fischer [16] and Wiesinger [17] by different methods.

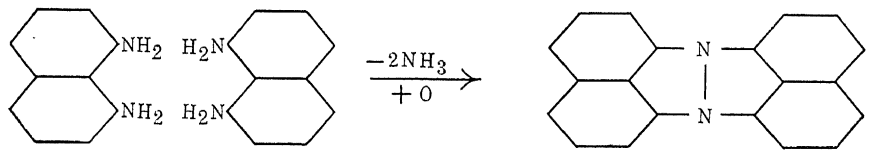
M-phenylenediamine—in aqueous solution gave a black precipitate which was collected after 28 days exposure. It crystallised from alcohol and also sublimed on careful heating in violet glistening needles melting at 128°, and was found to be identical with *2 : 6-diaminophenazine*. (Found N=27·1%).

P-phenylenediamine—in dilute hydrochloric acid solution began to deposit a black substance after 5 days' exposure and the precipitate went on increasing till the 106th day, after which it practically stopped. The substance is practically insoluble in all organic solvents except alcohol in which it is slightly soluble, and crystallises from this solvent in

microscopic black needles melting at 130°. It seems to be *3: 6-diaminophenazine* but this could not be confirmed for want of data. (Found N=26·8; $C_{12}H_{10}N_4$ requires N=26·6%).

Dimethyl-p-phenylenediamine—in dilute hydrochloric acid became of an intense violet colour after an exposure for 120 days, but hardly any precipitation occurred. The solution on investigation was found to contain a dyestuff of the azine series but it could not be definitely identified.

1:8-naphthalenediamine—in dilute hydrochloric acid began to deposit a dark brown crystalline substance in course of only two days' exposure and the deposit went on increasing till the 87th day when it was collected in sufficient amount. The substance crystallises from dilute alcohol in dark brown prisms and also sublimes on careful heating in chocolate coloured glistening needles which do not melt up to 300°. It dissolved in concentrated sulphuric acid with a violet colour, but was insoluble in dilute acids. Its properties point to its being in all probability *peridinaphthalene-azotide*, formed in accordance with the following scheme:



(Found N=9·6%)

Acetyl-p-phenylenediamine—in aqueous solution gave a dark orange-brown precipitate in course of only 4 days and the precipitate went on increasing till the 81st day when it was collected. It was crystallised from alcohol in light yellow needles melting at 239° and was identified to be *diacetyl-p:p'-diamidodiphenylamine.*

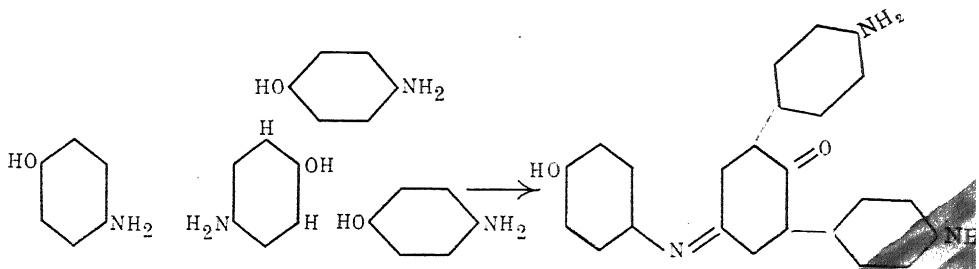
Aminophenols and their derivatives

O-aminophenol—in aqueous solution began to deposit an orange-coloured precipitate in course of only one day's exposure and this went on increasing till the 94th day when it was collected. The substance is easily purified by sublimation when it is obtained in brilliant crimson needles with a silky lustre. It dissolves in concentrated sulphuric acid with an indigo-blue colour and does not melt up to 300°. The product is identical with the compound $C_{24}H_{19}N_3O_2$ described by G. Fischer[18] and this was further confirmed by analysis. (Found N=11·0; $C_{24}H_{19}N_3O_2$ requires N=10·9%).

M-aminophenol—in aqueous solution began to deposit a brown precipitate after 6 days' exposure and the precipitate was collected after

62 days. The substance is practically insoluble in all organic solvents and therefore could not be crystallised from any one of them. It however sublimed on careful heating in small quantities as an orange-brown acicular needle like aggregates which did not melt up to 300°. The substance could not be identified.

P-aminophenol—in aqueous solution began to give a black precipitate after 6 days' exposure and the precipitate was collected after 70 days. The substance is easily soluble in alcohol and most of the organic solvents with an intense violet colour and from the alcoholic solution it is obtained in shining violet needles which do not melt up to 300°. It dissolves in concentrated sulphuric acid with an indigo blue colour and the same colour is also obtained with strong hydrochloric and glacial acetic acids. The reactions as well as the analysis of the substance point to the conclusion that it must be *pp'-dihydroxy-dianilino-indophenol* formed in accordance with the following scheme:



(Found N=11·4; $C_{24}H_{19}N_3O_2$ requires N=10·9%).

Dimethyl-m-amidophenol—gave only a trace of a precipitate after exposure for 125 days and is undoubtedly a very stable organic substance since it was recovered practically completely unchanged after that period.

Dimethyl-p-amidophenol—behaved exactly similarly to the above-mentioned compound.

O-anisidine—in dilute hydrochloric acid became dark red after 4 days' exposure and in about 10 days a precipitate began to collect at the bottom. This went on increasing till the 78th day when it was collected. The substance crystallised from alcohol and also sublimed in orange-brown needles which do not melt up to 300°. It dissolves in concentrated sulphuric and hydrochloric acids with an intense indigo-blue colour and from the solution the substance is reprecipitated unchanged on dilution. The substance has been identified to be *1:5-dimethoxy phenazine* (Found N=11·2; $C_{14}H_{12}N_2O_2$ requires N=11·6%).

P-anisidine—in hydrochloric acid solution behaved in a similar manner to the above compound and the product which sublimed in orange-brown needles and gave indigo-blue colour with concentrated sulphuric acid was identified to be *3:7-dimethoxy-phenazine.* (Found N=11·4 %).

O-phenitidine—behaved similarly and gave *1:5-diethoxy-phenazine.*

P-phenitidine—also behaved similarly and gave *3:7-diethoxy-phenazine.*

2:4-diamido phenol—in aqueous solution began to give a black precipitate in course of 7 days and the precipitate was collected after 63 days. The substance crystallises from alcohol in shining black needles which do not melt up to 300° and is very slightly soluble in most of the organic solvents. It gives a violet colour with concentrated sulphuric acid and crimson colour with acetic acid. The substance appears to be a derivative of phenazine but it could not be identified for want of confirmatory data.

Aromatic amino-acids

Anthranilic acid—in dilute hydrochloric acid solution became orange-red after 6 days' exposure and in ten days' time a dark coloured precipitate began to collect at the bottom. This was removed after 120 days' exposure and had the following properties: It crystallised from alcohol in yellow needles melting above 300°. It dissolved in sodium bicarbonate solution with effervescence and gave an orange-red colour with concentrated sulphuric acid. It was identified to be *phenazine-1:5-dicarboxylic* acid. (Found N=9·9; $C_{14}H_8O_4N_2$ requires N=10·4 %).

P-aminobenzoic acid—in dilute caustic soda solution became crimson-red after exposure for seven days, but the colour gradually faded and became light brown after two months. A colourless shining crystalline precipitate began to deposit after 10 days and this was collected after 85 days. On examination this was found to be the *disodium salt of pp'-azobenzene-dicarboxylic acid.* The free acid melted above 300° C and the diethylester at 114°.

M-aminobenzoic acid—in dilute caustic soda solution was practically unchanged after exposure for 125 days and is indeed a very stable substance.

Aromatic aldehydes

Vanillin—in dilute caustic soda solution was practically unchanged after an exposure of three months.

Beta-resorcylaldehyde—in dilute caustic soda solution behaved similarly to the above.

P-dimethyaminobenzaldehyde—in aqueous solution was unchanged even after three months.

P-aminobenzaldehyde hydrochloride—in aqueous solution began to give a yellow precipitate after 10 days' exposure and the precipitate was collected after 123 days. The substance crystallised from dilute alcohol in brown-yellow needles melting at 239° and was identified to be *pp'-dialdehydo-azobenzene.*

Miscellaneous compounds

Eosin—in 1% aqueous solution took nearly 75 days for complete decolorisation. A shining crystalline deposit which was formed on recrystallisation from water melted at 218° and was found to be identical with *2:4-dibromo-1: benzoylbenzoic acid.* The mother liquor contained good amounts of hydrobromic acid and gave a precipitate of silver bromide on treatment with silver nitrate in dilute nitric acid.

Erythrosin—in 1% aqueous solution took nearly 120 days for complete decolorisation. A shining crystalline deposit which was formed did not melt without decomposition and was probably *2:4-diiodo-1 : benzoylbenzoic acid* by analogy, but this could not be confirmed for want of data. In the mother liquor good amounts of free hydriodic acid were also found.

P-aminoacetophenone—in dilute hydrochloric acid turned reddish brown in course of only one day and in a week's time an orange-brown precipitate began to deposit. This was collected after 75 days. It crystallises from alcohol in yellow-brown needles melting at 180°, reduces ammoniacal silver nitrate and gives an orange-brown colour with concentrated sulphuric acid. It could not be identified.

Gallacetophenone—in dilute caustic soda solution was altogether unaffected even after exposure for 90 days. A very stable substance.

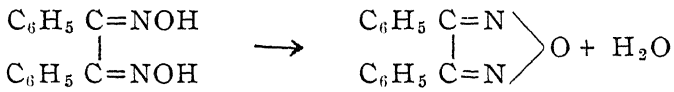
Phenylhydrazine—in aqueous solution become yellow and turbid in course of only one day's exposure and brisk evolution of gas (nitrogen) took place. In seven days' time a yellow-brown deposit was formed and this was collected after 56 days. The substance crystallises from alcohol in brownish yellow needles melting at 128° and contains nitrogen. It does not reduce Fehling's solution and is insoluble in dilute acids, alkalies and does not get diazotised or in any way affected by nitrous acid. It dissolves in strong sulphuric acid with a brown colour. The substance which apparently is a heterocyclic compound could not be identified.

2-amidothiazole—in dilute hydrochloric acid gave only a trace of a precipitate after exposure for three months which gave colour reactions

of phenazine derivatives. The quantity was too insufficient for further examination.

Sulpho-carbamide—in aqueous solution became turbid after one day's exposure and a pecipitate began to deposit fairly freely in course of a week. After exposure for 46 days the precipitate was collected and crystallised from carbon disulphide in fine yellow rhombic prisms melting at 225°. It was identified to be pure *sulphur*. The mother liquor was found to contain *carbamide*.

Benzil-α-dioxime—in dilute caustic soda solution in course of only ten days began to deposit colourless feathery crystals in large quantities and these were collected after 35 days. The substance was recrystallised from alcohol and melted at 94°. On examination the substance was found to be identical with *3 : 4-diphenyl-furazan*, formed in accordance with the following scheme :



Geometrical inversion

Maleic acid—in 1 % aqueous solution after exposure for 50 days was found to be completely converted into *fumaric acid*. No other product could be detected.

Cinnamic acid—in the form of its neutral sodium salt in 1 % aqueous solution after 50 days' exposure was found to be converted partially (17·2%) into *allo-cinnamic acid* which was separated from the excess of cinnamic acid by fractional crystallisation from water. The substance melted at 67·5°.

Itaconic, citraconic and tiglic acids—in aqueous solution remained unchanged even after 75 days' exposure, no geometrical inversion being noticeable in these cases.

Oleic and brassidic acids—in the form of sodium salts in aqueous solution became somewhat turbid after exposure for 50 days but no chemical change could be observed on examining the solutions.

Erucic acid—in dilute alcohol began to deposit a colourless precipitate in course of only 5 days and this went on increasing till the 38th day when it was collected. The substance crystallises from alcohol in colourless prisms melting at 118° and was found to be identical with *dihydroxyerucic acid*.

Aliphatic hydroxy acids

Malic acid—in one per cent aqueous solution was found to develop spores after only two days' exposure. The solution was therefore sterilised by boiling and the mouth of the flask covered with sterile cotton. After exposure for 123 days the solution was distilled and the strongly acid distillate on repeated extraction with ether and subsequent evaporation of the solvent gave a thick pale yellow liquid which gave all the reactions of *pyruvic acid.* It reduced Fehling's solution and ammoniacal silver nitrate, gave a yellow precipitate with phenylhydrazine and an insoluble lead salt. Pure pyruvic acid was obtained by decomposing the latter compound.

Citric acid—in aqueous solution after sterilisation underwent no change even after exposure for four months.

Tartaric acid—in aqueous solution was exposed for four months and then the solution was distilled. The neutral distillate on extraction with ether gave a minute quantity of a crystalline solid with strong aldehydic or ketonic properties. The quantity was however too insufficient for chemical examination. From the residue practically the whole of the tartaric acid was recovered unchanged.

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SOME ASPECTS OF NITROGEN FIXATION IN SOIL

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In a previous paper[1] it was shown that the ammonia content of soils is appreciably increased when energy-rich compounds like sugar, molasses, etc. are added to the soil, which has been properly aerated after the addition of sugars or molasses. Further work in this line is necessary as authorities in agriculture are still doubtful whether nitrogen fixation is possible in soil by the addition of energy-rich compounds. This is evident from the following lines[2] :—

"In view of the fact that the energy added to the soil is not directly available to the nitrogen fixing bacteria, and that small amounts of available nitrogen is always present in the soil, and the error in the laboratory determination of total nitrogen by Kjeldahl method is greater than the possible amount of nitrogen fixed by nonsymbiotic bacteria, we are still unable to decide the question definitely. Until our methods are more accurate, the question cannot be answered in a positive way. It has been stated, that the apparent gain of nitrogen in the soil is often due to drifting dust and plant residues or to soil variability." Exactly similar views have also been expressed by Russell.[3]

Moreover, uptil now it has been universally accepted that the nonsymbiotic nitrogen fixation in the soil is entirely a bacterial process, caused by the activity of azotobacter, clostridium etc. Our results, however, show definitely that even in the complete absence of bacteria under sterilized conditions, the oxidation of sugars by air leads to the formation of ammonia specially in presence of sunlight.

The experimental results recorded in the following tables, can be divided into four sets.

In the first set the soil has been mixed with different amounts of cane sugar or molasses and exposed to sunlight and air in enamelled dishes covered with ordinary glass plates. For the experiments in the dark the outer surface of the glass plates is covered with a thick coating of Japan-black enamel.

In the second set of experiments, known weights of molasses have been added to a definite area of soil, which has been carefully aerated by frequent turning over.

In the third set, weighed amounts of soil have been mixed with definite weights of molasses and made into heaps and exposed to air and light. For better aeration the heaps were frequently stirred. From time to time the total, ammoniacal and nitric nitrogen in 50 g. of the soil were estimated from all these sets. The results obtained have been expressed in grams per 100 g. of the soil.

In the fourth set of experiments, carefully sterilised soil (sterilisation effected in an autoclave under 20 lb. pressure for $2\frac{1}{2}$ hours) has been mixed with sterilised cane sugar and exposed to sunlight in quartz flasks and tubes with plugs of sterilised cotton wool for definite periods and the whole of the soil analysed for its ammoniacal, nitric and total nitrogen content after the necessary exposure.

Method of Analysis

For estimating the ammoniacal nitrogen present in the soil, 50 g. of the soil, which were dried in a steam oven, were treated with 5 g. of pure KCl and 5 g. of pure magnesium oxide and about 50 c.c. of water and distilled for six hours on a water bath, and at the same time a current of air purified by passing through a solution of ferrous sulphate, was aspirated. The ammonia was absorbed in two flasks containing standard solutions of sulphuric acid.

For the estimation of nitric nitrogen the soil, from which ammonia has been removed by the previous procedure, was treated with 1 g. of Devarda's alloy free from ammonia and nitrate and 25c.c. of 1% sodium hydroxide and left overnight for the reduction of nitrite and nitrate to ammonia. When the reduction was complete, the ammonia set free was estimated as in the first stage.

The total nitrogen was estimated according to the method of Robinson, McLean and Williams[4] by heating 5 g. of well dried and powdered soil with 20 c.c. concentrated sulphuric acid, 5 g. fused potassium sulphate and a few crystals of copper sulphate for four hours. The ammonium sulphate thus formed was estimated as before.

The sum of the ammoniacal and nitric nitrogen is known as *total available nitrogen* and the nitrogen obtained, according to the modified Kjeldahl method is the *total combined nitrogen.*

In all these experiments, the laboratory garden soil from the same locality was used.

The following results have been obtained :—

A. Experiments with cane sugar and soil in dishes

The cane sugar used in the experiments did not contain any combined nitrogen.

		Ammoniacal nitrogen.	Nitric nitrogen	Total available nitrogen	Ammoniacal nitrogen	Nitric nitrogen	Total available nitrogen
		UNSTERILISED			STERILISED		
Exposure for 78 hours spread over 13 days.	250 g. soil alone	0·00192%	0·002%	0·00392%	0·00224%	0·0024%	0·00464%
	20 g. sugar and 250 g. soil	0·00437	0·002	0·00637	0·00268	0·00224	0·00492
	20 g. sugar and 10 g. Na_2HPO_4 and 250 g. soil.	0 00267	0·0038	0·00656	0·00224	0·00224	0·00448
	20 g. sugar, 10 g.Na_2HPO_4 5 c.c. 1% $FeCl_3$ and 250 g. soil.	0·00384	0·00218	0 00602	0·00268	0·00224	0·00492
Exposure for 147 hours spread over 28 days.	250 g. soil alone.	0·00168	0·00234	6·00402	0 00238	0·00254	0·00492
	20 g. sugar and 250 g. soil.	0·01444	0 0025	0·01694	0·0094	0·00254	0·01194
	20 g. sugar, 10 g.Na_2HPO_4 and 250 g. soil.	0·0162	0·0024	0·01684	0·00838	0·00242	0·0108
	20 g. sugar, 10 g.Na_2HPO_4 5c.c. 1% $FeCl_3$ and 250 g. soil.	0·00886	0·0024	0·01126	0·0142	0·0024	0·0166
	Ditto in the dark.	0·007	0·00258	0·00958	0·00264	0·0025	0·00514
	250 g. soil alone indark.	0·00165	0·00246	0·00411	0·0025	0·00256	0·00506

		Ammoniacal nitrogen.	Nitric nitrogen.	Total available nitrogen.	Ammoniacal nitrogen.	Nitric nitrogen.	Total available nitrogen.
		Unsterilised.			Sterilised.		
Exposure for 230 hrs. spread over 38 days.	250. g. soil alone.	0·00169%	0·00222%	0·00392%	0·00206%	0·00242%	0·00448%
	20 g. sugar and 250 g. soil.	0·01296	0·00264	0·0156	0·00792	0·0025	0·01042
	20 g. sugar and 10 g. Na_2HPO_4 and 250 g. soil.	0·01224	0·00264	0·01488	0·00626	0·00321	0·00947
	20 g. sugar, 10 g. Na_2HPO_4 5c.c. 1% $FeCl_3$ and 250 g. soil.	0·01224	0·00264	0·01488	0·00626	0·00322	0·00948
Exposure for 240 hours spread over 68 days.	Ditto in the dark.	0·0064	0·00258	0·00898	0·00246	0·00258	0·00504
	250 g. soil alone in dark.	0·00172	0·00226	0·00398	0·0025	0·00224	0·00474
	250 g. soil alone.	0·00172	0·0024	0·00412	0·00185	0·00254	0·00439
	250 g. soil and 20 g. sugar.	0·00642	0·00584	0·01226	0·00244	0·0025	0·00494
	20 g. sugar, 10 g. Na_2HPO_4 and 250 g. soil.	0·00604	0·00474	0·01078	0·00284	0·00246	0·0053
	20 g. sugar, 10 g. Na_2HPO_4, 5c.c. 1% $FeCl_3$ and 250 g. soil.	0·00582	0·00578	0·0116	0·00244	0·00224	0·00468
Kept for 68 days.	20g. sugar, 10g. Na_2HPO_4, 5 c.c. 1% $FeCl_3$ and 250 g. soil (dark).	0·0082	0·00558	0·0137	0·00246	0·00258	0·00504
	250 g. soil alone in dark.	0·00178.	0·00226,	0·00404,	0·00244,	0·00224,	0·00468.

B. Experiments with molasses and soil in dishes

In the following table corrections have been applied for the amount of ammonia introduced with molasses :—

(The molasses contained 0·001% ammoniacal nitrogen and no nitric nitrogen)

	Amount of molasses added per kilogram soil.	Ammoniacal nitrogen.	Nitric nitrogen.	Total available nitrogen.	Total combined nitrogen.
Exposure 76 hours.	Original.	0·000734%,	0·0035%,	0·00423%,	0·0362%.
	5 g.	0·000738,	0·004,	0·004738,	0·0362.
	10 g.	0·00072,	0·004,	0·00472,	0·0362.
	20 g.	0·000725,	0·004,	0·00472,	0·0362.
	40 g.	0·00071,	0·004,	0·004708,	0·0362.
	75 g.	0 0014,	0·004,	0·0054,	0 0398.
	100 g.	0·00134,	0 004,	0.00534,	0·0473.
	150 g.	0·00112,	0·004,	0·00512,	0·05.
	190 g.	0·00102,	0·004,	0·00502,	0·053.
Exposure 161 hours.	5 g.	0·000944,	0·004,	0·004944,	0·036.
	10 g.	0·00096,	0·0038,	0·00476,	0·036.
	20 g.	0·00106,	0·0038,	0·00486.	0·036.
	40 g.	0 00113.	0·0038,	0·00493,	0·036.
	75 g.	0·0022,	0·0038,	0·006,	0·038.
	100 g.	0·00222,	0·0038,	0·00602,	0·c046.
	150 g.	0·00216,	0·0038,	0·00596,	0·049.
	190 g.	0·0021,	0·0038,	0·0059,	0·052.
Corresponding in dark.	10 g.	0·00111	0·00338	0·00448	0·0362
	20 g.	0·00097,	0·00376,	0·00475,	0·0362.
	40 g.	0·00043,	0·00376,	0·00410,	0 0362.
Exposure = 279 hours.	5 g.	0·00136,	0·00412,	0·00548,	0·036.
	10 g.	0·00148,	0·00412,	0·0056,	0·036.
	20 g.	0·00159,	0·00412,	0·00571,	0·036.
	40 g.	0·00184,	0·00412,	0·00596,	0 0362.
	75 g.	0·0022,	0·004,	0·0062,	0·0382.
	100 g.	0 002,	0·00324,	0·00524,	0·046.
	150 g.	0·00104,	0·00284,	0 00388,	0·0492.
	190 g.	0·00037,	0·00224,	0·00261,	0·0527.
Corresponding in dark.	10 g.	0·00074,	0·00324,	0·00398,	0·036.
	20 g.	0·00051,	0 0031,	0·00361,	0·036.
	40 g.	0·000414,	0 00282,	0·00323,	0·036.

Plots of land of area 36 sq. ft. were treated with 1½, 3 and 6 kilograms of molasses. The following table shows the nitrogen content of the soil at various periods. It has been found by analysis that the control field does not indicate any appreciable increase in the nitrogen content during the time taken up by these experiments.

C. Experiments with molasses added to field soil

With 1½ kilograms of molasses per 36 sq. ft. Analysis of the molasses:—

Ammoniacal nitrogen. 0·001%. Nitrate nitrogen. nil.

	Ammoniacal nitrogen.	Nitric nitrogen.	Total available nitrogen.	Total combined nitrogen.	Analysed on.
Original.	0·00216%,	0·00232%,	0·00448%,	——	
Aëration with molasses after 15 days.	0·00312,	0·00242,	0·00554,	0·0417,	17-2-1935.
Aëration with molasses after 30 days.	0·00608%,	0·0052%,	0·01128%,	0·0409%,	4-3-1935
Aëration with molasses after 45 days.	0·00642,	0·00574,	0·01216,	0·0437,	20-3-1935

With 3 kilograms of molasses per 36 sq. feet.

Original ...	0·00062,	0·0069,	0·00752,	0·0434,	22-12-1934
Aëration with molasses.	0·00062,	0·0069,	0·00752,	0·0618,	9-1-1935
Insufficient aëration.	0·00062,	0·0069,	0·00752,	0·0455,	„

	Ammoniacal nitrogen.	Nitric nitrogen.	Total available nitrogen.	Total combined nitrogen.	Analysed on.
With 3 kilograms of molasses per 36 sq. feet.					
Aëration with molasses.	0·00086,	0·00864,	0·00950,	0·0619,	24-1-1935
Insufficient aëration.	0·00046,	0·00682,	0·00728,	0·0442,	„
Aëration with molasses.	0·001,	0·00932,	0·01032,	0·061,	8-2-1935
Insufficient aëration.	0·00043,	0·0065,	0·00693,	0 045,	„
Aëration with molasses.	0·00156,	0·0092,	0·01076,	0·062,	23-2-1935
Insufficient aëration.	0·00042,	0·0064,	0·00682,	0·046,	„
Aëration with molasses.	0·00182,	0·00929,	0·01111,	0·062,	10-3-1935
Insufficient aëration.	0·00052,	0·0064,	0·00692,	0·046,	„
Aëration with molasses.	0·00182,	0·0092,	0·01102,	0·0646,	26-3-1935
Insufficient aëration.	0·00068,	0·00648,	0·00716,	0·041,	„
With 6 kilograms of molasses per 36 sq. feet.					
Original ...	0·007,	0·00854,	0·01544,	0·0432,	2-2-1935
Aëration with molasses.	0·00875,	0·00784,	0·01659,	0·0458,	17-2-1935
Ditto	0·01186,	0·0076,	0·01946,	0·045,	4-3-1935
Ditto	0·01058,	0·00724,	0·01782,	0·0472,	20-3-1935

D. Molasses added to soil in heaps

A heap of soil weighing 167 kilograms (A) was treated with 12 kilograms of molasses, and another heap weighing 174 kilograms (B) was treated with 6 kilograms of molasses and frequently stirred after adding small amounts of water.

	Ammoniacal nitrogen.	Nitric nitrogen.	Total available nitrogen.	Total combined nitrogen.
Original. Treated with molasses on 18-2-1935.	0·00865%,	0·00582%,	0·01447%,	0·0458%.
A analysed on 18–3-1935.	0·01646,	0·00594,	0·0224,	0·0538.
B „ „	0·00934,	0·00594,	0·01528,	0·0504.
A analysed on 18-4-1935.	0·01400,	0·0058,	0·0198.	0·0540.
B „ „	0·0116,	0·0058,	0·0174,	0·0512.

E. Experiments with cane sugar and soil in sterilised condition

Original.	0·00155,	0·0035,	0·00505,	
Soil 50 g. + Cane sugar 4g. Exposure 60 hrs. in 250c.c. quartz flask.	0·00233,	0·004,	0·00633,	
Soil 50 g. + Cane sugar 2 g. Exposure 150 hrs. in 250c.c. quartz flask.	0·0056,	0·0042,	0·0098,	
Soil 50 g. + 1 g. Na_2HPO_4 + Cane sugar 4 g. Exposure 150 hrs. in 250c.c. quartz flask.	0·00468,	0·00442,	0·0091,	
Soil 50 g. + Cane sugar 4 g. + 1 g. Na_2PHO_4 Exposure 302 hrs. in quartz test tube.	0·00102,	0·0035,	0·00452,	before the exposure
	0·00127,	0·00462,	0·00589,	after the exposure

	Ammoniacal nitrogen.	Nitric nitrogen.	Total available nitrogen.	Total combined nitrogen.
Original.	0·000734%,	0·0035%,	0·004234%,	0·00458%,
Soil 100 g. + water 50c.c. + cane sugar 1 g. Exposure 145 hrs. in 250c.c. quartz flask.	0·00116,	0·00402,	0·00518,	0·0466.
Soil 100 g. + sugar 2 g. + water 50c.c. Exposure 284 hrs. in 250c.c. quartz flask.	0·00155,	0·00386,	0·00541,	0·0486.
Ditto with 4 g. sugar	0·00175,	0·00386,	0·00561,	0·0486.

The results recorded in the foregoing tables show that in all cases, when either cane sugar or molasses are added to the soil, which is properly aërated, there is an appreciable increase in the ammonia content. The amount of ammonia goes on increasing to a limiting value with the increase of exposure. The nitrate content also increases with time, specially in aërated soils. When the exposure is continued further, denitrification sets in. It is interesting to note here that previous workers, determined only the total nitrogen of the soil after the addition of energy-rich compounds, and as the difference in the total nitrogen is not high before and after the addition of the energy-rich compounds to the soil, they were doubtful regarding the fixation of nitrogen in the soil by the addition of energy-rich compounds. But as we have estimated, both the available (ammoniacal and nitric nitrogen) and the total nitrogen, we have been able to detect the increase of available nitrogen in all cases when energy-rich organic compounds are added to well aërated soils.

Another far-reaching conclusion can be drawn from our experimental results, which show, that under identical conditions, the amount of ammoniacal nitrogen is always greater in the soil mixed with energy-rich compounds and receiving sunlight, than in the dark. If this type of nonsymbiotic nitrogen fixation had been entirely a bacterial process as has been generally believed, the amount of ammonia formed should not differ in the vessels kept in light or in the dark. Moreover, the results obtained in the sterilised condition show an increase in ammonia, when the soil is mixed with cane sugar and exposed to sunlight under

completely sterilised conditions. It seems established, therefore, that just as bacteria can fix nitrogen in the soil in presence of energy-rich compounds, similarly even in the absence of bacteria, the photo-oxidation of the energy-rich compounds, leads to the fixation of nitrogen. It appears, therefore, that in tropical countries in ordinary soils the fixation of atmospheric nitrogen by the addition of energy-rich compounds is partially bacterial and partially photo-chemical. The oxidation of energy-rich organic compounds by air either by light absorption, or by bacterial action causes the fixation of atmospheric nitrogen in the soil. The recent experiments of Dhar and Mullik on the influence of temperature on nitrogen fixation by a fairly pure culture of azotobacter thriving in mannitol medium, as the energy-rich substance show the optimum temperature for nitrogen fixation to be 35° as will be evident from the following results obtained at different temperatures :—

Temperature :—(ammonia formed in milligrams).

Days.	0°	15°	25°	30°	35°	40°
4	nil	1·28	2·41	3·21	4·11	6·88
8	"	2·61	4·36	6·53	7·79	10·61
12	"	4·13	6·80	8·76	11·76	12·1
16	"	5·01	8·93	11·75	14·3	14·5
20	"	6·2	11·15	14·5	17·13	14·86
24	"	7·18	12·81	16·45	19·45	15·17
28	"	8·01	14·83	18·11	21·17	15·29
32	"	8·89	15·61	18·76	22·79	15·33
36	"	9·85	16·5	19·01	22·91	15·31

It appears, therefore, that in the tropical countries in summer months, when the soil temperature is as high as 70° nonsymbiotic nitrogen fixation in presence of energy-rich compounds may be more of a photo-chemical nature than of bacterial.

There is a practical aspect of these investigations, because very little definite knowledge is available regarding the amounts of nitrogen that can be fixed in nonsymbiotic process. Miller[5] has stated the problem in the following words :—

" Wide use is being made in systems of agriculture of the bacteria, which work with legumes, but the nitrogen fixing power of those which work outside the plant is as yet not utilised extensively by man, since the methods of controlling them are not well understood."

In many of our field experiments the amounts of ammoniacal nitrogen was three times greater when molasses have been added and the soil

aërated than that was originally present in the soil. From a simple calculation it can be shown that the amount of nitrogen added to the soil in this way can be 152·4 kilograms. per acre which is equivalent to the addition of 356 kilograms of ammonium sulphate when only 0·0001% fixation occurs.

Our results show that increased aëration leads to an increase in the ammonia content of the soil mixed with the cane sugar or molasses. Moreover, we have observed ammonia formation when air is passed through a solution of glucose or cane sugar mixed with an inductor like ferrous or cerous hydroxide. The induced oxidation of cane sugar or glucose liberates energy which is utilised in the fixation of nitrogen.

We are of opinion that the energy set free in the oxidation of energy rich compounds by air either through the agency of bacteria (azotobacter), or sunlight or inductors is utilised in the following endothermal reaction $N_2+O_2=2\ NO-43{\cdot}2$ Cal. The nitric oxide is further oxidized to nitrate which seems to be the first product in nitrogen fixation. The iron compounds present in the soil help this oxidation. Recently Dhar and Mukerji[6] have shown that nitrates and carbohydrates (but not ammonium salts and carbohydrates) in presence of sunlight and TiO_2 can readily form amino acids with copious production of ammonium salts. Hence the nitrate, which is likely to be the first product in nitrogen fixation in soil in presence of air, is reduced to ammonia by the action of carbonaceous substances with the simultaneous formation of amino acids in small amounts and that is why ammonia is observed in nitrogen fixation. Waywick and Woodhouse[7] have also obtained evidence of amino acid formation in nitrogen fixation in soils.

The recent work of Burk[8] seems also to be in favour of the view that nitrate and not ammonia is the first product in nitrogen fixation.

Summary

1. When cane sugar is added to sterilised and unsterilised soils and exposed to light and air, there is appreciable increase in the ammoniacal nitrogen content; with unsterilised soil the ammoniacal nitrogen is nine times greater than that originally present in the soil.

The amount of NH_3 in presence of light is always greater than that in the dark.

2. By the addition of molasses to soils, which have been properly aërated the ammoniacal nitrogen also increases; in this case the ammoniacal nitrogen is three times greater than that originally present in the soil, when 3600 kilograms of molasses are added per acre of land. When the

aëration of the soil is insufficient the increase of ammonia is less and the soil becomes acidic.

3. Under completely sterilised conditions when cane sugar is mixed with soil, there is also an increase in the ammoniacal nitrogen. The total available nitrogen (ammoniacal and nitrate nitrogen) in the soil was 0·005, but after exposure to sunlight in a quartz flask with cane sugar it became 0·0098. It seems established therefore, that just as bacteria can fix nitrogen in the soil in presence of energy-rich compounds, similarly even in the absence of bacteria, the photo-oxidation of the energy-rich compounds, leads to the fixation of nitrogen.

It appears, therefore, that in tropical countries in ordinary soils, the fixation of atmospheric nitrogen by the addition of energy-rich compounds is partially bacterial and partially photo-chemical. The oxidation of energy-rich organic compounds by air either by induction or light absorption, or by bacterial action, causes the fixation of atmospheric nitrogen in the soil.

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ON EIGHT NEW SPECIES OF THE GENUS *CYCLOCOELUM* BRANDES FROM NORTH INDIAN SNIPES*

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Introduction

So far not a single species of the genus *Cyclocoelum* has been recorded from India. In July 1932 Dr. H. R. Mehra suggested to me to examine the snipes available at Allahabad for collection and investigation of different members of the family Cyclocoelidae. Accordingly I dissected more than hundred snipes and obtained a large number of specimens belonging to eight new species of the genus *Cyclocoelum* which are described in this paper. The worms are exclusively parasitic in the air sacs or the body cavity. Some immature forms, however, were found in the small intestine of the hosts. The degree of infection varies considerably in different periods of the year in various species of the host birds which belong to the family Scolopersidæ. The snipes first appeared infected in the month of September when the largest number of parasites obtained from a single host was only three and the rate of infection only thirty per cent. The rate and degree of infection increase from September onwards, reaching the maximum in November when as many as fifteen worms were obtained from a single snipe, and the rate of infection reached sixty per cent. *Glottis nebularia*, the common green shank known as "Chaha" is the most favourable host for a large number of species of *Cyclocoelum*. Though the degree of infection is not very high, a large number of birds are found infected with as many as four different species. *Capella gallinago gallinago*, the common fan tail snipe, known as "Chahe" is another bird which is found commonly infected.

* This paper was submitted as a thesis in lieu of two papers for the M.Sc. examination in Zoology of the Allahabad University in 1933.

The infection in this case appears rather early in the year and the maximum rate is sixty per cent; but never more than five specimens of *Cyclocoelum* were obtained from a single host. In *Tringa erythropus*, the common dusky red shank, known as "Lal tang ka chaha" the infection is very rare; from it only two specimens were obtained and less than thirty per cent of these birds were found infected, but the infected birds always yielded quite a large number of specimens. As many as fifteen specimens were obtained from a single host. The parasites could not live for more than six hours in normal salt solution or nutritive solutions.

I am much indebted to Dr. H. R. Mehra under whose supervision this work was carried on. He not only suggested the problem and guided me in this work but he was also kind enough to translate the papers in French for me. I have great pleasure to acknowledge my sincerest thanks to him. I am also indebted to Dr. D. R. Bhattacharya for giving me facilities in the department to carry on this work. My thanks are also due to Mr. S. C. Verma for his kind help and permission to work up part of the material already in his possession.

Previous work on the Family Cyclocoelidae Kossack, 1911

In 1782 Goeze described two species which he believed to have only one sucker. Schrank (1788) published a paper which was a mere catalogue of the species. If we do not take into account these two workers, Zeder (1800, 1803) was the first who studied the group thoroughly and used the name Monostome for these parasites on account of the absence of the ventral sucker. In 1801 he gave the first account of *C. mutabile*, the type species of the genus *Cyclocoelum*. The group of monostomes which formed a main division in the classification of the Digenea, called Monostomata is maintained even now by many workers on the group, though its validity has been well criticised by several recent authorities. Zeder assigned five species, *i.e.*, *M. ocreatum*, *M. bombynæ*, *M. verrucosum*, *M. prismaticum* and *M. mutabile* to this then newly created group Monostomata. Later on the first two were removed to the Distomata; third was grouped under the sub-family Notocotylinæ while the last two were assigned to the sub-family Cyclocoelinae.

Rudolphi in 1808 in his synopsis Entozoorum agreed with Zeder in the system of classification which he adopted and described the anatomy of *M. ellepticum* obtained from the lungs of *Rana maculata*. Von Siebold (1835) gave the first complete description of these monostomes and described *M. mutabile* Zeder, 1801, giving an

account of early stages of its life-history as seen in the egg before it is discharged from the uterus. Diesing, 1850, reorganised this group including all the species known upto that time. Von Beneden, 1861, worked out the anatomy of *M. verrucosum* Frolich reviewing the anatomy of *M. mutabile* Zeder, *1801*, and described a cercaria which he considered to be the larval form of *M. verrucosum* Frolich.

Monticellie's work in 1892 published in two papers gave an account of the genus *Notocotyle* Diesing, 1850, and *M. cymbium* Diesing, 1850.

Brandes in 1892 was the first to propose the genus *Cyclocoelum* to include *M. mutabile* Zeder, *M. flavum* Mehlis, *M. tringae* Brandes, *M. ellepticum* Ruldolphi and *M. arcuatum* Brandes and gave its diagnosis. Looss in 1899 accepted this genus with *M. mutabile* as the type species. But his contemporary Lühe in 1900 in his review of the work of Looss did not accept the generic name *Cyclocoelum* because the family name Monostomidæ could not be used without a type genus Monostoma according to the rules of nomenclature. Looss in 1901 explained that *M. prismaticum* was the type of the genus Monostoma Zeder which Lühe did not accept, but on the other hand continued to use the generic name Monostoma instead of *Cyclocoelum* Brandes.

Stossich in 1902 on the suggestion of Brandes divided the group Monostomata into two sub-families, Notocotylinæ and Cyclocoelinæ. In the latter he included four genera, *Cyclocoelum* Brandes, *Hæmatotrephus* Stossich, *Opthalmophagus* Stossich and *Typhlocoelum* Stossich. Kossack in 1911 raised the sub-family Cyclocoelinæ to the rank of the family Cyclocoelidæ in which he included the following genera: *Cyclocoelum* Brandes, *Allopyge* Johnston, *Hæmatotrephus* Stoss., *Hyptiasmus* Koss., *Opthalmophagus* Stoss., *Typhlocoelum* Stoss., *Spaniometra* Koss., and *Bothriogaster* Fuhrm. Skrjabin, 1913, created a new genus *Tracheophilus* which he placed in the family Cyclocoelidæ and also described the anatomy of *C. orientale* from *Glottis nebularius.*

Harrah classified the Monostomata into four families: Cyclocoelidæ Kossack, 1911, Notocotylidæ Lühe, 1909, Collyriclidæ Ward, 1917, and Heronimidæ Ward, 1917, and divided the family Cyclocoelidæ into three sub-families: Cyclocoelinæ Stoss., 1902, Typhlocoelinæ Harrah, 1922, and Opthalmophaginæ Harrah, 1922. In the sub-family Cyclocoelinæ he included three genera: *Cyclocoelum, Hæmatotrephus* and *Hyptiasmus*; in the sub-family Typhlocoelinæ, two genera: *Typhlocoelum* and *Tracheophilus*; and in the sub-family Opthalmophaginæ three genera: *Opthalmophagus, Bothriogaster* and *Spaniometra.*

Witenberg in his first memoir published in 1923 created two genera *Problemogenus* and *Promptenovum*, a sub-genus *Mediopharyngeum* and a species *Cyclocoelum* (*Antepharyngeum*) *goliath*, all belonging to the sub-family Cyclocoelinæ. But in a subsequent paper in 1926 in which he included his previous work he dropped the above-mentioned genera and the sub-genus and accepted the two sub-families Cyclocoelinæ Stoss., and Typhlocoelinæ Harrah, dropping the third sub-family, *i.e.*, Opthalmophaginæ Harrah, 1921. He also divided the sub-family Cyclocoelinæ into seven tribes, *i.e.*, *Wardianea, Haematrotrephea, Cyclocoela, Hyptiasmea, Opthalmophagea, Bothriogasterea* and *Contracoela*, each consisting of five genera.

This lengthy classification was criticised in 1926 by Joyeux and Baer who did not consider the characters distinguishing the different genera and tribes to be of even specific importance. They did not accept also the sub-families Cyclocoelinæ and Typhlocoelinæ saying that the presence or absence of outgrowths in the intestinal cæca at the most is of generic importance. According to Joyeux and Baer the family Cyclocoelidæ contains only three genera, namely, *Cyclocoelum* Brandes, 1892, *Typhlocoelum* Stoss., 1902, and *Spaniometra* Kossack, 1911. The other genera included in this family by the previous workers, the joint authors have reduced to the rank of species, giving a list of synonyms, dropping some new names used for the old ones. Morishita in 1930 agrees in principle with the classification given by Joyeux and Baer, considering it more concise and suitable for practical purposes. He included sixteen species under the genus *Cyclocoelum*. I follow Joyeux and Baer and Morishita in the classification of the family and think that the genera now included in it are based on constant and deep morphological characters. As a large number of old genera have been dropped or reduced to the rank of species the systematic study of the group has become clearer.

Diagnosis of the genus Cyclocoelum Brandes, 1892.

Endoparasitic trematodes of middle to large size with elongated muscular body and smooth body-wall. Mouth opening terminal or subterminal, oral sucker rudimentary or absent; ventral sucker absent except in *C. distomatum* Morishita, 1924, and *C. vagum* Morishita, 1924. Pharynx well developed and muscular; œsophagus long and muscular; intestinal cæca simple and continuous with each other in the form of an arc near posterior end of body. Excretory bladder between posterior intestinal

arc and posterior body wall with medio-dorsal terminal pore. Genital opening median and ventral to pharynx. Cirrus sac well developed containing vesicula seminalis and ductus ejaculatorius. Vitellaria laterally situated, between body wall and intestinal cæca. Genital glands intracæcal in posterior half of body forming the points of triangle or in straight line one behind the other; ovary between two testes or anterior to both. Receptaculum seminis present or absent. Laurer's canal absent. Receptaculum seminis uterinum present or absent. Uterus well developed filling intracæcal space in front of posterior testis and much convoluted in more or less regular folds, sometimes overlapping intestinal cæca. Eggs numerous, without polar filament, usually containing well developed miracidia with characteristic double eyespots.

Key to the Indian species of the genus Cyclocoelum described in this paper

1.	Ovary anterior to testes	*C. nebularium*
	Ovary between testes	2.
2.	Ovary in line with testes	*C. straightum*
	Ovary not in line with testes	3.
3.	Ovary lobed	*C. lobatum*
	Ovary compact	4.
4.	Uterine coils not overlapping cæca	*C. capellum*
	Uterine coils overlapping cæca	5
5.	Uterine coils closely situated; ratio between testes and ovary 5 : 2	*C. allahabadi*
	Uterine coils well separated; ratio between testes and ovary 3 : 2	*C. indicum*
	Receptaculum seminis and receptaculum seminis uterinum well developed.	*C. mehrii*
	Receptaculum seminis and receptaculum seminis uterinum absent.	*C. erythropis*

Cyclocoelum nebularium, n. sp.

A dozen specimens of this species were collected from the air sacs mostly from the abdominal ones of the common green shank—*Glottis nebularia*, near Allahabad. They are medium sized, 10—13* long and

*All measurements are given in mm.

2—3·5 in maximum breadth which lies slightly anterior to the region of the gonads, *i.e.*, at the beginning of the posterior 1/5 part of body. From the maximum breadth the body tapers gradually to a slightly rounded anterior end, measuring 0·85 in the region of the pharynx. In the region of the gonads it is more or less straight with parallel sides ending in a broadly rounded end, where it measures 2—3·3 in breadth.

The pharynx is well developed, 0·25—0·35 long and 0·2—0·25 broad. I agree with Monticelli and Harrah in considering it as the pharynx and not the oral sucker as Braun in 1901 thought it to be. It does not show the radial, inner and outer layers of muscle fibres as are present in the sucker but on the contrary it has the typical musculature of the pharynx. The œsophagus is S-shaped, but in some specimens it is more or less straight, two to three times the length of the pharynx, roughly 0·511—0·512 long and 0·085 broad, and bifurcates 1·125—1·275 behind the anterior end. The intestinal cæca, devoid of diverticula, run parallel to the body wall in a slightly irregular course and join with each other posteriorly in an arc 0·285 in front of the anterior end. The excretory bladder lies between the intestinal arc and posterior extremity of the body with hinder ends of the vitellaria on its sides, measuring 0·56—0·85 in length and 0·085—0·185 in breadth. It opens to the exterior through a pore situated dorsally at the posterior end.

The genital glands lie in the intercæcal region enclosed by the intestinal arc and form three points of a triangle with the ovary as the apex. The two testes lie obliquely behind the ovary. The anterior testis is round, situated to the side opposite to that of the ovary, 0·5—0·6 distance behind it and measures 0·7—1·0 in diameter. It is almost equal in size to the posterior testis except in a few individuals in which the latter may appear more elongated due to pressure.

The posterior testis lies somewhat median or little shifted to the same side as the ovary, obliquely behind the anterior testis from which it is separated by the transverse vitelline duct. It is generally rounded, somewhat elongated, measuring 0·71—1·2 in greatest length and 0·51—0·93 in greatest breadth. The uterine coils do not pass behind the anterior testis, between it and the posterior testis as is usually the case in the genus. In immature specimens of hardly more than 7·0 length the testes do not measure more than 0·45 in diameter. The vasa efferentia arise from the anterior margins of the testes near the outer side and unite cephalad and mediad to the posterior testis behind the ovary to form the long vas deferens which takes a more or less straight course to the cirrus sac in which it dilates into a more or less straight vesicula seminalis. The latter fills up

the basal 2/3 part of the cirrus sac and opens to the exterior at the common genital pore. The cirrus has not been observed in the protruded condition. The cirrus sac is tubular and dilated posteriorly, extending from the genital pore to the anterior end of the intestinal bifurcation and measuring 0·8–1·0 in length and 0·2—0·3 in maximum breadth. The anterior narrower 1/3 part of the sac in some specimens is bent in a crescent-shaped manner while in others it is more or less straight.

The ovarian complex occupies a position anterior to both the testes, a rare position for the genus, which was previously considered as characteristic of the genus *Hæmatotrephus*. The ovary, almost rounded with entire margin lies 1·8 in front of the hinder end, either to the right or left side of body, alternating with the anterior testis. It is smaller than the testes, measuring 0·31—0·41 in diameter, *i.e.*, 4/7 of the anterior and 4/9 of the posterior testis in diameter. The short oviduct arises from the posterior margin of the ovary and runs backwards to enter the shell gland complex, which is almost rounded with fringed margins, measuring 0·3 in diameter. The receptaculum seminis is situated inside the ovary near the median line, measuring 0·15—0·35 in length and 0·05—0·11 in breadth. Morishita in his paper in 1924 calls this organ as the ootype because of the absence of sperms in it. Though the sac is devoid of sperms I do not agree with Morishita, because the ootype, as is well known, is a slightly dilated part of the oviduct surrounded by the shell glands. The receptaculum seminis opens into the oviduct immediately before it becomes surrounded by the shell glands on the side opposite to that on which the common vitelline duct enters it. The Laurer's canal is absent. The uterus at its commencement is swollen to form the receptaculum seminis uterinum which lies in the form of a loop between the anterior testis and the ovary, and is always filled with sperms. The uterine convolutions in the form of well developed loops are directed with their outer ends almost posteriad up to the intestinal bifurcation. In front of the latter the uterus runs in more or less straight course, opening externally at the genital pore.

The vitellaria are laterally situated, confined to the extreme edges of the body and are composed of small follicles extending anteriorly to the middle of the intestinal bifurcation and posteriorly to the lateral walls of the excretory bladder. In one specimen they are joined with each other posteriorly forming an arc just in front of the excretory bladder; while in other specimens though they are not joined at the posterior end they reach quite close to each other. Anteriorly the vitellaria do not end at the same level; the gland situated to the same

side as the ovary extends more anteriorly. The transverse vitelline ducts arise at about 1/8th body length from the posterior end. The one situated to the ovarian side is shorter, arises more anteriorly than its fellow and runs in a more or less straight course close in front of the posterior testis, sometimes overlapping its anterior margin. The yolk reservoir lies median close in front of the posterior testis and enters the shell gland mass by a short common vitelline duct. The longitudinal vitelline ducts lie surrounded by the vitelline follicles, laterally or dorsally to the intestinal cæca.

The eggs are large, thick-shelled without operculum and show miracidia with characteristic double eye spots, measuring 0·12 × 0·087 in size. The unripe eggs without miracidia measure 0·101 × 0·085 in size.

Remarks :—

Before 1926 all the species having the ovary in front of testes were included in the genus *Hæmatotrephus*. Joyeux and Baer in 1926 and Morishita in 1930 dropped the latter genus and included all the species belonging to it in the genus *Cyclocoelum*. The new species resembles *C. brazilianum* Stoss. and *C. tringæ* Brandes, in the testes being obliquely situated behind the ovary, but it differs from them in the size of the body which is almost twice as large as that of *C. tringae*, in the larger size of the pharynx, absence of the oral sucker and the greater ratio between the size of the ovary and testes. It differs further from *C. brazilianum* in having the testes of equal size and the posterior extent of the cirrus sac, which reaches quite close to the anterior wall of the intestinal bifurcation. It differs from *C. wilsoni*, *C. triangularium* and *C. taxorchis*, in which too the ovary lies anterior, in the oblique position of the testes. *C. nebularium*, n. sp., however, occupies an intermediate position between *C. brazilianum* and *C. tringæ* on the one hand and *C. wilsoni*, *C. taxorchis* and *C. triangularium* on the other, resembling the first two in the oblique position of the testes and the last three in the equal size of the latter.

Cyclocoelum straightum, n. sp.

Only one specimen of this species was obtained during the month of November 1932 from the abdominal air sac of *Glottis nebularia*, caught from the fields of Phulpore near Allahabad. Subsequently about hundred specimens of different genera of the Scolopersidæ were examined but none was found infected with this species. Body long, dorso-ventrally flattened, in pressed specimens 25 long and 4·3 in maximum breadth in the region of anterior testis, *i.e.*, at about 1/6th. body length from posterior end; tapering in front and behind anterior testis, 2·5 in breadth in

region of posterior testis and 1·2 in that of pharynx ; anterior end bluntly pointed, posterior end broadly rounded ; body wall devoid of spines.

Oral sucker very feebly developed, barely visible, measuring 0·15 in length and 0·11 in breadth, *i.e.*, 1/3 of pharynx in size. Ventral sucker absent.

Mouth subterminal leading by a funnel shaped cavity into pharynx of 0·344 length and 0·425 breadth, situated 0·45 from extreme anterior end ; œsophagus S-shaped or straight, 1·0 in length and 0·11 in breadth ; intestinal bifurcation 1·88 distance from anterior end ; cæca without diverticula, situated laterally parallel to the body wall and uniting behind to form an arc at 0·3 distance in front of hinder end. Excretory pore dorsal and terminal ; excretory bladder horizontally situated between intestinal arc and posterior end of body with terminal ends of vitellaria on its sides and measuring 0·68 in length and 0·11 in breadth.

Gonads in posterior one sixth part of body, with ovary between testes and in line with them and not forming points of a triangle. Both the testes are separated from one another by ovary, shell gland complex and three uterine coils ; anterior testis to right side, 0·5 from right wall, 0·26 from right cæcum, 0·52 in front of ovary, 3·5 in front of posterior end and 1·7 in front of posterior testis. It is transversely elongated and pear shaped with entire margin, measuring 1·05 in length and 0·68 in maximum breadth ; posterior testis situated mesially 0·75 in front of posterior end, 0·25 in front of intestinal arc and 0·5 behind ovary, separated from the latter by transverse vitelline ducts, shell gland mass and uterine coils and measuring 1·25 in length and 0·99 in maximum breadth. Vasa efferentia arise from anterior ends of testes ; vas deferens traced from anterior one-third of body to cirrus sac, straight bulbous vesicula seminalis filling posterior two-third part of cirrus sac, ductus ejaculatorius narrow and tubular in anterior one-third part or neck of cirrus sac ; pars prostatica, prostate gland cells and cirrus not observed. Cirrus sac curved and nearly flask-shaped with an anterior transversely lying tubular one-third part, the neck, of 0·28 length and 0·06 breadth and posterior two-thirds dilated part of 0·55 length and 0·27 breadth reaching near intestinal bifurcation, ending 0·15 distance in front of it.

Ovary almost median or a little to right side, 0·75 from anterior testis and 0·5 from posterior testis, nearly spherical with entire margins and slightly pressed posteriorly by receptaculum seminis, 0·45 in length and 0·41 in breadth, *i.e.*, almost one-third of posterior testis ; oviduct arises from posterior lateral corner of ovary ; shell gland mass, of more or less oval shape with fringed margins, median, to left side of ovary, 0·68 in

length and 0·58 in breadth, *i.e.*, about one and a half size of the latter; receptaculum seminis, 0·35 long and 0·5 broad, situated immediately behind ovary, slightly pressed with its long axis to the latter. The ootype has a little broader calibre than the oviduct and runs a straight course surrounded by the shell gland mass. Laurer's canal absent as usual in the family. Receptaculum seminis uterinum large filled with sperms and a few ova, approximately 1·0 long and 0·25 broad, situated horizontally to left side between left cæcum and shell gland mass; uterine convolutions filling almost the whole body in the form of slightly separated loops with ends directed outwards towards the cæca, extending forward up to intestinal bifurcation; beyond the latter uterus more or less straight.

Vitellaria extend from middle of intestinal bifurcation to excretory bladder; transverse vitelline ducts arise from posterior 1/8 length of vitellaria but not at the same level, the right one at higher level than left; the right duct runs transversely almost straight for 1·45 distance before it joins its fellow behind shell gland mass; left transverse duct which arises 1·3 in front of posterior end of body runs straight for 0·5 and then turns upwards for a distance of 1·0 before it joins its fellow to form the small rather inconspicuous yolk reservoir which immediately opens in shell gland mass.

Ova thick-shelled, non-operculate with fully developed miracidia; unripe ova yellowish brown, 0·116 in length and 0·06 in breadth; ripe ova dark brown, 0·136 in length and 0·068 in breadth.

Cyclocoelum capellum, n. sp.

About a dozen specimens of this species were obtained mostly from the cervical air sacs of the common fan tail snipes—*Capella gallinago* near Allahabad, India. The infection seems to be seasonal and rare as the parasites were obtained before September and after November. The number of worms found in a single host was never more than three. Body 1·7—2·5 in length and 3·5—4·6 in maximum breadth at the beginning of the posterior one-fourth part of body; breadth 3 in region of posterior testis, 1·1—1·2 in region of pharynx. Oral sucker subterminal and rudimentary, 0·08 in length and 0·04 in breadth; pharynx 0·275 in diameter, almost rounded at 0·085 distance behind anterior end; œsophagus S-shaped or straight, approximately 0·3—0·5 in length and 0·1 in breadth; intestinal bifurcation 0·65 behind anterior end; cæca without diverticula joining each other posteriorly to form an arc at 0·2 in front of posterior end. Excretory bladder of 0·55—1·1 breadth and 0·06 length horizontally parallel to posterior wall of intestinal arc; excretory pore dorsal and terminal.

Gonads in posterior fifth of body forming three points of a triangle; anterior and posterior testes separated from one another by five pairs of uterine coils; anterior testis at a distance of 4·5 from posterior end, 2·3 from posterior testis and 1·75 from ovary, situated to right side near intestinal cæcum, slightly smaller than posterior testis, measuring 0·8 in length and 0·6—0·8 in breadth; posterior testis median, much lobed, close in front of intestinal arc, 1·2 in front of posterior end and 0·9 behind ovary, separated from the latter by vitelline ducts, shell gland mass and receptaculum seminis uterinum measuring 1·1 in length and 0·7—0·88 in breadth. Vasa efferentia join at about middle of body to form vas deferens which runs in an irregular course; vesicula seminalis followed by a thin narrow ejaculatory duct enclosed in cirrus sac opens into genital pore at posterior margin of pharynx. Cirrus sac flask-shaped with basal portion hardly reaching intestinal bifurcation ; neck of cirrus sac 0·2 long and 0·015 broad and saccular portion 0·4 long and 0·17 broad. Ovary to the left side 0·8 from left body wall and 0·2 from left cæcum, more or less spherical with entire margins, 0·37 – 0·55 in length and 0·37 – 0·5 in breadth; shell gland mass immediately behind ovary pressed against it at its posterior end, rounded with fringed margins and 0·45 in diameter, receptaculum seminalis somewhat pear-shaped, situated to inner side of ovary, 0·3—0·4 in length and 0·15 – 0·2 in breadth; receptaculum seminis uterinum filled with sperms and a few ova, measuring 0·7 in length and 0·25 in breadth; uterus turning upwards and outwards in front of posterior testis and thrown into double loops throughout its anterior course, confined to intercæcal region never overlapping cæca; metraterm straight from posterior end of intestinal bifurcation to genital pore. Vitellaria laterally situated parallel to bodywall, between it and intestinal cæca ending anteriorly not at the same level, the one situated to ovarian side extending a little more forwards upto region of cirrus sac, posteriorly they terminate 0·25 in front of lateral ends of excretory bladder; right transverse vitelline duct arises at 2·3 from posterior end and runs almost straight for 2·0, left transverse vitelline duct arises at a lower level. *i.e.*, 1·70 from posterior end and is much shorter running straight for 0·6 ; yolk reservoir of 0·15 length opens dorsally in shell gland mass near the origin of uterus. Ova in posterior one-fourth part of body brownish yellow, 0·12 in length and 0·064 in breadth, while in anterior 3/4 part of body ripe dark brown and having fully developed miracidia, 0·13 × 0·068 in size.

Remarks :—

This species differs from all the species in the following combination of characters: (1) uterus confined to intercæcal region, (2) peculiar

shape of cirrus sac with its narrow neck, (3) in the size ratio between oral sucker and pharynx, (4) large size of yolk reservoir, (5) size of gonads, pharynx, œsophagus, cirrus sac and ova. It differs from *C. allahabadi* in the uterine coils being confined to the intercæcal zone, in which it resembles *C. mutabile* Zeder. *C. cuneatum* Harrah and *C. leidyi* Harrah and *C. toratsuqumi* Morishita. But it differs from them in the lobed character of its posterior testis, ratio of oral sucker to pharynx, relative size of the gonads and the testes being widely separated.

Cyclocoelum allahabadi, n. sp.

Only five specimens were obtained mostly from the thoracic air sacs of the common red shank snipes—*Tringa erythropus*—near Allahabad, India. The infection is very rare as out of thirty snipes examined only four were found infected. The number of parasites in a host is generally one and never more than two. The infection is found only in the rainy season and early part of winter. Size 17 in length, 2·5--3 in maximum breadth at beginning of posterior fourth part, breadth in the region of posterior testis 1·3—1·7 and in that of pharynx 0·68—0·85, posterior end rounded, anterior end bluntly pointed; subterminal mouth surrounded by a more or less laterally flattened oral sucker of 0·07 × 0·2 size, situated 0·05 behind anterior end; pharynx spherical of 0·28 diameter; œsophagus S-shaped, 0·51 long and 0·085 broad; intestinal bifurcation at 0·85 distance behind anterior end; cæca lateral, passing into each other at hinder end to form an arc at 0·25 in front of posterior end.

Gonads in posterior 1/6th part of body; ovary in between and alternating with testes; anterior testis close inside and touching right cæcum at 1·7 from posterior end, 1·1 from hinder testis and 0·8 from ovary, more or less spherical, measuring 0·8—0·85 in length; posterior testis 0·6—0·7 behind ovary from which it is separated by transverse vitelline ducts, spherical; vas deferens from middle of body to cirrus sac; straight bulbous vesicula seminalis followed by ductus ejaculatorius; genital pore ventral at posterior end of pharynx; cirrus sac club-shaped consisting of a narrow duct like anterior part of 0·2 length and 0·07 breadth and a posterior dilated part of 0·4 length and 0·18 breadth extending upto middle of intestinal bifurcation.

Ovary situated to the side opposite to that of anterior testis, 0·35 inside corresponding cæcum and 1·3 inside corresponding lateral body wall, 0·4 in front of posterior testis and 0·8 behind anterior testis, with entire margins and 0·3—0·35 × 0·2—0·25 in size; receptaculum seminis

well developed, inside ovary near median line and 0·25×0·14 in size; shell gland mass, 0·34 in diameter, with fringed margins, posterior to left side of ovary and not exactly between it and posterior testis as is usual in the genus; uterus runs downwards between ovary and posterior testis and then turns upwards to continue its forward course; convolutions arranged transversely in close contact with one another filling the body between intestinal bifurcation and posterior testis; metraterm straight from intestinal bifurcation to genital pore.

Vitellaria lateral, restricted to extreme edges throughout body length, extending over cæca at places and reaching uterine coils, not extending to the same level anteriorly, right transverse vitelline duct arises 0·45 behind anterior testis and runs downwards in a more or less straight course for 0·7 distance till it reaches anterior margin of posterior testis and turns slightly upwards for 0·4—0·5 distance to join left vitelline duct which arises 1·4 in front of posterior end; common vitelline duct of 0·2 length enters shell gland mass near junction of receptaculum seminis with it. Ova thin shelled and operculate; immature ova yellowish brown, 0·118×0·08 in size; mature ova dark brown, 0·119×0·08 in size.

Remarks:—

This species differs from *C. capellum*, n. sp. in the uterine coils extending over intestinal cæca; in *C. capellum* the uterus is restricted to intercæcal zone. The general topography of the gonads is of Mutabile type and in this respect it resembles *C. elongatim* Harrah, *C. obliqum* Harrah, *C. microstomum* Creplin, *C. obscurum* Leidy, *C. problematicum* Stoss., *C. ovapunctatum* Stoss., *C. vicarium* Kossack, *C. orientalis* Skrjabin, *C. leidyi* Harrah, *C. pseudomicrostomum* Harrah, *C. cuneatum* Harrah, *C. macrorchis* Harrah and *C. mutabile* Zeder. From all the above mentioned species it differs in the size of the body and size ratio of gonads. It differs from *C. mutabile*, *C. cuneatum* and *C. leidyi* in the uterus overlapping cæca. It resembles closely *C. microstomum*, *C. pseudomicrostomum*, *C. obscurum*, and *C. vicarium* in having testes of equal size. It, however, differs from the last two in having pharynx larger than oral sucker and from the first two in position of genital pore, in the size ratio between testes and ovary, in body size and size of eggs.

Cyclocoelum indicum, n. sp.

Only two specimens of this species along with a few specimens of *C. nebularium*, n. sp. were obtained from the body cavity of one common green shank snipe—*Glottis nebularia*—in November, 1932. Length 20—27

and maximum breadth 4—4·5 at the beginning of posterior fourth of body *i.e.*, at a distance of 2·5 in front of anterior testis. From this point forward the body tapers gradually to a small rounded anterior end; posterior end bluntly rounded, 2·5—3 in breadth across posterior testis. Mouth subterminal, surrounded by a poorly developed rudimentary oral sucker of 0·1 diameter, situated at 0·1 from anterior end; pharynx 0·25 from anterior end almost three times the size of oral sucker, 0·28 in diameter; straight œsophagus 0·58—0·7 long and 0·085—0·13 broad; intestinal bifurcation 1·2 distance from anterior end, cæca simple, lateral near body wall, uniting with each other at 0·2 distance in front of posterior end to form an arc. Excretory bladder behind and parallel to posterior wall of intestinal arc, 0·55 in breadth, excretory pore dorsal at hinder end.

Testes as usual in posterior region of body confined to intercæcal zone; posterior testis not large enough to fill intestinal arc, more or less spherical with irregular margins, 0·85—0·93 in diameter, situated 0·85 in front of hinder end, 0·15 in front of posterior intestinal arc and 1·0 behind ovary; anterior testis 1·8 in front of ovary and 2·2 in front of posterior testis separated from the latter by four or five uterine coils, to the left side touching intestinal cæcum and spherical with regular margins, almost equal to posterior testis in size measuring 0·85 in diameter; vas deferens runs in anterior half of body, straight vesicula seminalis; ejaculatory duct in narrow neck of cirrus sac; genital pore in mid-ventral line behind pharynx; cirrus sac club-shaped with anterior one-third part narrow and tubular of 0·25 length and 0·06 breadth and posterior two-thirds dilated saccular part of 0·5 length and 0·2 breadth.

Ovary between testes and alternating with them forming three points of a triangle at 1·0 from anterior testis, 0·4 from right cæcum and 0·7 from right body wall, spherical with entire margins, 0·5—0·6 in diameter, and separated from posterior testis only by shell gland mass and transverse vitelline duct and uterine coils; shell gland mass about the size of ovary and pressed against the right wall of the latter, spherical with fringed margins and 0·5 in diameter; receptaculum seminis elongated with irregular margins inside ovary and 0·34×0·17 in size. Vitellaria dense irregular masses of follicles confined to lateral margins of body extending right from lateral ends of excretory bladder to middle of œsophagus but not ending at the same level anteriorly, right extending more forwards than the left; transverse vitelline ducts arise 2·6 in front of posterior end, *i.e.*, from posterior fifth of vitellaria; right transverse duct soon after its origin about level of posterior wall of shell gland mass bends and runs

closely outside and behind receptaculum seminis uterinum for 1·0 before it joins the left duct; receptaculum seminis uterinum of 0·5 × 1·0 size situated horizontally behind shell gland mass, between it and right transverse vitelline duct; uterine coils widely separated extending over cæca and reaching body wall; metraterm straight from intestinal bifurcation to genital pore; immature ova of yellowish brown colour and 0·102 × 0·06 size filling first third part of uterus; mature ova, thin shelled with fully developed miracidia, measure 0·12 × 0·068 in size.

Remarks:—

C. indicum, n. sp., has the same topography of genital organs as characterises the Mutabile group. Among the so far known species of this group it resembles only the well-known species *C. microstomum* Creplin and *C. pseudomicrostomum* Harrah, but it differs from them in size of body, ratio between pharynx and oral sucker, size of ova and position of genital pore. It is distinguished from *C. allahabadi*, on account of greater breadth of body, size of ova, widely separated uterine coils and presence of receptaculum seminis uterinum. It differs from *C. erythropis*, n. sp., in size of body, large size of ovary and ova, presence of receptaculum seminis, shape and size of cirrus sac, position of genital pore and peculiar arrangement of uterine convolutions.

Cyclocoelum erythropis, n. sp.

A large number of specimens were obtained from the air sacs of the common dusky red shank—*Tringa erythropus* near Allahabad. It is one of the commonest species of the genus met with at Allahabad from October to January. The largest number of parasites obtained from a single host was ten. Length 7·5—17 and maximum breadth 1·7—2·3 in the region of anterior testis, *i.e.*, at the beginning of hinder fifth body; posterior end rounded and 1·3 – 1·7 in width; anterior end bluntly pointed, measuring 0·5— 0·9 in breadth in the region of pharynx. Oral sucker, 0·15 in length and 0·1 in breadth, feebly developed and subterminally situated, 0·1 behind anterior end. Pharynx 0·15—0·25 in diameter; œsophagus more or less straight, 0·5—0·6 in length and 0·085 in breadth, intestinal bifurcation 1·0 behind anterior end; cæca simple, uniformly wide, 0·15 in breadth, not so wide as in other species; intestinal arc 0·15 in front of hinder end. Excretory bladder horizontally parallel to posterior wall of intestinal arc and longer than that in other species, measuring 0·12—0·15 × 0·19—0·34 in size; excretory pore median dorsally situated at hinder end.

Gonads in posterior one-fifth part of body; posterior testis not filling entire intestinal arc, median, 0·2 in front of the latter, spherical with regular margins and 0·5—0·68 in diameter; anterior testis 1·2—1·5 in front of posterior testis and separated from it by four or five uterine coils, more or less spherical with entire margins and almost equal to posterior testis in size, measuring 0·5—0·68 in diameter; vas deferens traced only in anterior fourth body; vesicula seminalis straight and inside cirrus sac; genital pore ventral just behind pharynx, cirrus sac somewhat club-shaped with anterior fourth part of 0·085—·12 × 0·07 size narrow and tubular, and the rest of 0·255—0·36 × 0·13—0·18 size dilated and reaching middle of intestinal bifurcation. Ovary very small, spherical with entire margins, 0·19—0·29 in diameter, near right side 0·4—0·6 inside corresponding body wall, in between but opposite to the testes, 1·3 behind anterior testis and 0·5—0·7 in front of posterior testis from which it is separated only by shell gland mass and a single coil of uterus; receptaculum seminis uterinum and Laurer's canal absent; shell gland mass spherical; uterus runs forwards in closely situated coils extending laterally over cæca and reaching vitellaria in posterior three-fourths of body, in front of which it runs almost straight to intestinal bifurcation; metraterm short.

Vitellaria laterally pressed against body wall from intestinal bifurcation to lateral margins of excretory bladder, extending more forward on the side towards ovary; transverse vitelline ducts arise between shell gland mass and posterior testis, the one towards ovary much shorter, one-third of the other in length; yolk reservoir prominent, of 0·31 length.

Thin shelled ova in first one-fifth part of uterus, yellowish brown and without miracidia, 0·1 × 0·08 in size.

Remarks:—

This species also belongs to Mutabile group of Morishita. In having testes of nearly equal size it resembles *C. microstomum*, *C. pseudomicrostomum*, *C. macrorchis*, *C. vicarium*, *C. allahabadi*, n. sp., and *C. capellum*, n. sp., but differs from *C. macrorchis* and *C. vicarium* in having pharynx larger than oral sucker. It differs from the others:—(1) in the absence of receptaculum seminis, and receptaculum seminis uterinum, (2) small size of ovary and ova, (3) size of body, (4) characteristic arrangement of uterine coils which uniformly cover anterior half of intestinal cæca, (5) shape and extent of cirrus sac and (6) narrow breadth of intestinal cæca.

Cyclocoelum mehrii, n. sp.

This is one of the commonest species met with in the common fan tail snipe—*Capella gallinago gallinago*. The infection does not appear to

be seasonal though it is highest in the months of November and December when the greatest number of parasites obtained from a single host was twelve and the rate of infection more than sixty per cent. In other months of the year the maximum number of parasites obtained was four and the rate of infection not more than thirty per cent. Length 18—28 and maximum breadth 3·4—5 in front of anterior testis, *i.e.*, at the beginning of posterior 1/6 part of body; breadth in region of posterior testis 2·5—3·5 and that of pharynx 1·1—1·2; anteriorly and posteriorly the body narrows down till it ends into rounded ends; subterminal oral sucker very rudimentary, visible only in sections, 0·085—0·1 in diameter, *i.e.*, roughly one-third of pharynx; pharynx muscular, spherical, 0·27 in diameter, 0·25 behind anterior end; œsophagus S-shaped, roughly 0·6—0·8 in length and 0·1 in breadth; intestinal bifurcation 0·7—0·9 behind anterior end; intestinal arc 0·4 in front of posterior end. Excretory bladder horizontally parallel to intestinal arc, 0·68—0·85 in length and 0·18—0·25 in breadth; excretory pore in mid-dorsal line at hinder end.

Gonads in posterior one-fifth part of body; posterior testis 0·15 in front of posterior intestinal arc, spherical, entire and 0·9—1·3 in diameter; anterior testis more or less spherical, 0·85 × 0·7—0·1 in size, lateral, inside and touching one of the cæca, 0·3—0·5 from the corresponding lateral body wall and 2·5—3·3 in front of posterior testis from which it is separated by four to five uterine coils; cirrus sac retort-shaped, extending behind anterior wall of intestinal bifurcation; vesicula seminalis of 0·42 × 0·18 size; ductus ejaculatorius of 0·21 length and 0·07 breadth; genital pore ventral to middle of pharynx. Ovary between testes towards the side opposite to anterior testis, at 0·75 distance from corresponding lateral body wall, 2—2·8 behind anterior testis, 1—1·5 in front of posterior testis and separated from the latter by shell gland mass, transverse vitelline ducts, large receptaculum seminis uterinum and a coil of uterus, spherical, entire and 0·4—0·6 in diameter; shell gland mass more or less spherical with fringed margins, 0·4—0·68 × 0·4—0·6 in size, close behind ovary; receptaculum seminis small, pear-shaped, inside ovary, 0·35—0·42 × 0·17—0·22 in size, opening by a narrow duct into oviduct before entrance of the latter into shell gland mass.

Vitellaria dense and confined to extreme edges of body overlapping cæca, extending from middle of intestinal bifurcation to lateral ends of excretory bladder; transverse vitelline ducts arise at different levels, one towards ovary at a higher level, *i.e.*, 0·2 in front of posterior end, other 0·12 in front of posterior end; yolk reservoir short, situated in the loop formed by receptaculum seminis uterinum and opens by a fairly

large, 0·7 long common vitelline duct into shell gland mass on its inner side before opening of receptaculum seminis and origin of uterus; receptaculum seminis uterinum runs transversely upto anterior margin of posterior testis and then turns forwards to form a loop which lies between and in the same line with posterior testis and ovary, uterine coils well separated from one another, overlapping cæca at places and extending forwards to intestinal bifurcation filling the body more or less completely; metraterm straight, from intestinal bifurcation to genital pore; immature ova in first third part of uterus 0·115×0·058 in size, mature ova thin shelled with fully developed miracidia, dark brown, 0·12×0·068 in size.

Remarks:—

C. mehrii has the topography of the Mutabile type, *i.e.*, the gonads form three points of a triangle with ovary in between testes. In unequal size of the testes and lateral extent of uterine coils it resembles *C. problimaticum* but differs from the latter in size of body, oral sucker being rudimentary and much smaller than pharynx and in the ratio of the testes and ovary, *i.e.*, 2 : 1 in *C. mehrii* and 3 : 1 in *C. problimaticum*. It is the largest species known in the genus measuring 28 in length and is further distinguished by the large size of the gonads, ova, receptaculum seminis uterinum and pharynx. It differs from *C. macrorchis* and *C. vicarium* in having unequal testes, from *C. mutabile* and *C. leidyi* in the uterine coils passing over intestinal cæca and from *C. obscurum* and *C. ovopunctatum* in having pharynx much larger than the oral sucker.

I dedicate this species to Dr. H. R. Mehra, under whom I had the pleasure of carrying on this work.

Cyclocoelum lobatum, n. sp.

Only one specimen of this parasite was obtained from the thoracic air sacs of each of the two common snipes, green shank—*Glottis nebularia* examined. Size moderate, length 1·3 and maximum breadth 2·4 slightly in front of anterior testis, *i.e.*, at the beginning of posterior fourth of body; posterior end bluntly rounded, 2·0 wide in the region of posterior testis; anterior end rounded 0·85 in width in the region of pharynx. Oral sucker not seen in toto mount; pharynx muscular, spherical of 0·27 in diameter; straight œsophagus of 0·68 length and 0·1 width; intestinal bifurcation 0·8 behind anterior end; intestinal arc 0·45 in front of posterior end. Excretory bladder comparatively small but broad between posterior end and intestinal arc, 0·35 in length and 0·17 in width with terminal ends of

vitellaria on the sides; excretory pore median and dorso-terminal. Gonads in posterior one-fourth of body, ovary between testes and on the side opposite to that of anterior testis; posterior testis median, almost spherical entire and 0·6—0·75 in length and 0·55—0·7 in breadth; anterior testis slightly elongated and equal in size to posterior testis, inside and touching the corresponding intestinal cæcum, 1·4—1·5 in front of posterior testis from which it is separated by a compact mass of uterine coils; vesicula seminalis saccular, straight in posterior two-thirds of cirrus sac. Genital pore at middle of pharynx. Cirrus sac comparatively small reaching posteriorly just behind anterior end of intestinal bifurcation, anterior one-third narrow tubular part 0·16×0·07 in size and basal two-thirds dilated sac like 0·33×0·2 in size.

Ovary 0·15 inside the corresponding cæcum, 1·2 behind anterior testis, close in front of posterior testis, separated from the latter only by transverse vitelline ducts, lobed and 0·4—0·5×0·35—0·55 in size; shell gland mass, 0·3×0·17 in size, with fringed margins; receptaculum seminis inside ovary near median line, 0·2×0·15 in size, entering by a narrow neck at anterior margin of shell gland mass close to entrance of the oviduct. Vitellaria laterally situated from posterior end of cirrus sac right up to lateral margins of excretory bladder, ending anteriorly at the same level; transverse vitelline duct of the same side as the ovary arises at a higher level, *i.e.*, at 1·75 in front of posterior end; other transverse duct arises 1·5 in front of hinder end. The two ducts unite just behind ovary and laterally to shell gland mass to form a small rather inconspicuous common vitelline duct which enters the latter opposite to the opening of receptaculum seminis.

Uterus emerges from posterior margin of shell gland and runs upwards into a densely crowded mass of coils filled with ova up to anterior limit of hinder one-fourth of body in front of which coils become less dense and well separated, terminating near intestinal bifurcation; receptaculum seminis uterinum absent; metraterm anterior to intestinal bifurcation. Ova thin shelled and non-operculate; mature ova thin shelled with fully developed miracidia of dark brown colour, 0·119×0·068 in size.

Remarks :—

The topography of the genital organs is that of the Mutabile type. It resembles *C. microstomum*, *C. pseudomicrostomum*, *C. macrorchis*, *C. vicarium* in having the testes of equal size but differs from them in having a large pharynx, in the extremely reduced condition of oral sucker and lobed form of the ovary. It differs from all the known species of the genus in the posterior extent of the uterus, uterine coils forming a compact

mass and the lobed condition of the ovary. The vitellaria in this species extend anteriorly almost to the same level in both the arms, which is rather unusual for the genus. This species is also distinguished by the absence of receptaculum seminis uterinum.

Explanation of Plates

Fig. 1. *Cyclocoelum nebularium.*
Fig. 2. *C. straightum.*
Fig. 3. *C. capellum.*
Fig. 4. *C. allahabadi.*
Fig. 5. *C. indicum.*
Fig. 6. *C. erythropis.*
Fig. 7. *C. mehrii.*
Fig. 8. *C. lobatum.*

Lettering

C.P. Cirrus Pouch.
G.P. Genital Pore.
I.A. Intestinal Arc.
I.C. Intestinal Cæcum.
O. Ovary.
O.S. Oral Sucker.
Oes. Oesophagus.
Ph. Pharynx.
R.S.U. Receptaculum Seminis Uterinum.
R.S. Receptaculum Seminis.
S.Gl. Shell Gland.
T. Testis.
U. Uterus.
V.D. Vitelline Duct.
Vit. Vitellaria.

Table I—Showing diagnostic characters of the species of *Cyclocoelum* hav-

Species.	Size.	Pharynx.	Oral sucker.	Ventral sucker.	Genital pore.
C. vagum Morishita 1930.	9—10 × 3—3·5 Greatest breadth in posterior third.	Spherical; 0·29.	Feebly developed.	Very rudimentary.	At the centre of anterior intestinal arc.
C. *distomatum* Morishita 1930.	5·5—8 × 3·9—3·5 Greatest breadth in the posterior fourth.	Slightly elongated 0·18 × 0·107—0·13.	Well developed.	Rudimentary but visible in toto mount.	At centre of intestinal arc.
C. straightum, n. sp.	25×4·3 Greatest breadth in the posterior sixth.	Broader than long 0·34 × 0·42.	Feebly developed.	Absent.	At posterior region of pharynx.

ing the ovary between the testes and in line with them, *i.e.*, *C. vagum* type.

Oesophagus.	Cirrus sac.	Vitellaria.	Uterine coils.	Ova.	Host.
Short coiled dorso-ventrally.	Short, tadpole like, mostly behind intestinal bifurcation.	Between cirrus sac and posterior intestinal arc.	Not reaching cæca.	0·067—0·077 × 0·037—0·043	*Chrysolophus picta.* Japan.
S-shaped; 0·3 long.	Spindle-shaped, behind intestinal bifurcation.	Between intestinal bifurcation and posterior margin of intestinal arc.	Uterine ends directed somewhat posteriad; slightly overlapping cæca.	0·050—0·060 × 0·03—0·04	*Phasianus scintillas.* Japan.
S-shaped or straight	Anterior 1/3 tubular and posterior saccular, ending just in front of intestinal bifurcation.	From middle of intestinal bifurcation to excretory bladder, *i. e.*, behind intestinal arc.	Uterine ends directed more or less posteriad extending laterally beyond cæca.	0·136 × 0·068	*Glottis nebularia.* India.

Table II—Showing the Measurements of the species of Cyclocoelum having ovary anterior to testes.

Species.	Size.	Pharynx Size; ratio with oral sucker.	Testes; ratio between posterior testis and ovary.	Genital pore.	Cirrus sac.	Ova.	Host.
C. tringæ Brandes, 1892.	5—6×1·65	0·168—0·3× 0·195—0·35; 1:2.	oblique, unequal, rounded and regular; 2 : 1.	behind pharynx.	to anterior end of intestinal bifurcation.	0·13× 0·064	*Helodroma ochropus.*
C. brazilianum Stossich, 1902.	11·5—14·5 ×3·0—3·55	0·235×0·28; 2: 3.	oblique, unequal, almost rounded, 0·625 in diameter, 3 : 2.	at posterior of pharynx.	ends in front of intestinal bifurcation.	0·161× 0·084	*Totanus flavipus, T. melanolenchus, Pavoncella pugnox and Helodroma solitarius.* South America.
C. nebularium, n. sp.	10—13× 2·0—3·5	0·25— 0·35× 0·204—0·25 oral sucker rudimentary; 4: 1.	oblique, equal, 0·7—1·2; 9: 4.	posterior to pharynx.	to anterior wall of intestinal bifurcation.	0·1—0·12× ×0·085 —0·087	*Glottis nebularia.* India.
C. taxorchis Johnston, 1916.	8—14× 2·28—3·5	0·285×0·192; 2 : 1.	at the same level, irregular, equal, 1·36 ×0·97; 3 : 1.	in level with posterior end of pharynx.	to middle of intestinal bifurcation.	0·117—0·1 39×0·05 9—0·06	*Himantopus leucocephalus* and *Gallinago gallinago.* Australia.
C. wilsoni Harrah, 1921.	12×3	0·298×0·269; oral sucker 0·37 ×4; 3 : 4.	at the same level, spherical, 0·99×0·91 in diameter; 3 : 7.	middle of pharynx.	to middle of intestinal bifurcation.	0·15× 0·076	*G. wilsoni;* intestine. America.
C. triangularium. Harrah, 1921.	8×2	0·248×0·215; nearly equal.	at the same level, spherical, equal, 0·243; 6 : 10.	at posterior end of pharynx.	to middle of intestinal bifurcation.	0·132× 0·075	*Tringa maculata.* America.

Table III.—Showing diagnostic characters of the species of *Cyclocoelum*—in which uterus is restricted to the intercæcal zone.

Species.	Size.	Pharynx; ratio with oral sucker.	Testes; ratio with ovary.	Cirrus sac.	Genital pore.	Ova.	Host.
C. mutabile Zeder, 1800.	16—18 × 4—4·5	Larger than oral sucker.	Rounded, entire unequal, posterior larger: posterior testis and ovary 2 : 1.	Basal two-thirds slightly dilated, reaching middle of intestinal bifurcation.	At anterior margin of pharynx.	0·117 × 0·066	*Fulica atra.*
C. cuneatum Harrah, 1924.	10·5—12 × 2·5—3·5	Both equal, 0·19—0·22 in diameter.	Anterior spherical, posterior flattened anterio-posteriorly, entire; or posterior larger than anterior; anterior testis and ovary 4 : 3.	Club-shaped, straight reaching anterior wall of intestinal bifurcation.	At the anterior end of pharynx.	0·115 × 0·066	*Gallinago delicata*, abdominal cavity.
C. leidyi Harrah, 1924.	16—18 × 4—4·5	Oral sucker larger than pharynx, pharynx 0·281—0·3; 3 : 1.	Spherical entire equal, 0·87—0·91 in diameter; 5 : 2.	Straight with basal two-thirds much dilated, reaching much behind intestinal bifurcation.	At middle of pharynx.	0·117 × 0·066	*Gallinago wilsoni*, thoracic cavity.
C. toratsugumi Morishita, 1924.	11—14 × 2·5—4	Oral sucker absent, pharynx 0·21 — 0·27 × 0·23—0·25.	Spherical, or elliptical, entire, unequal posterior larger 3 : 2.	Retort-shaped, reaching middle of intestinal bifurcation.	At middle of pharynx.	0·13—0·14 × 0·078—0·082	*Oreocinela daumaurea*, body cavity.
C. capellum n. sp.	17—25 × 3·5—4·6	Oral sucker smaller than pharynx; pharynx 0·275 in diameter; 2 : 7.	Lobed, spherical, unequal; posterior larger; anterior testis and ovary 2 : 1.	Flask-shaped, posterior two-thirds dilated hardly reaching intestinal bifurcation.	At posterior margin of pharynx.	0·13 × 0·068	*Capella gallinago.* cervical air sacs.

Table IV—Showing the characteristics of *Cyclocoelum* species—testes of equal size forming with ovary between them the points of a triangle; uterus not restricted to intercæcal zone.

Species.	Size.	Pharynx; ratio with oral sucker.	Testes; ratio of testes with ovary.	Cirrus sac.	Genital pore.	Uterine coils.	Vitellaria.	Ova.
C. microstomum Creplin, 1829.	13–15 × 4–5	650–700 U in diameter; 3 : 2.	4 : 3	Retort-shaped; reaching posteriorly to middle of intestinal bifurcation.	At middle of pharynx.	Partly overlapping cæca.	Between cirrus sac and excretory bladder; partly overlapping cæca.	0·10 × 0·06
C. pseudomicrostmum Harrah, 1922.	13–14 × 4–4·5	0·778–0·910 × 0·745–0·844; 7: 6.	5 : 2	Extending almost to posterior wall of intestinal bifurcation.	At forward end of pharynx.	Rarely overlapping cæca.	Between cirrus sac and excretory bladder; overlapping cæca and the lateral folds of uterus.	0·102 × 0·051–0·066
C. allahabadi, n. sp.	17·0 × 2·5–3	0·28 in diameter; 7 : 5.	5 : 2	Club-shaped. reaching behind anterior wall of intestinal bifurcation.	At posterior end of pharynx.	Overlap cæca and reach vitellaria at many places.	From middle of intestinal bifurcation to excretory bladder; partly overlapping cæca.	0·12 × 0·08
C. erythropis, n. sp.	7·5–14 × 1·7–2·3	0·15–0·25 in diameter 8 : 7.	7 : 3	Club-shaped reaching behind anterior wall of intestinal bifurcation.	Slightly behind pharynx.	Reaching laterally upto vitellaria.	Between cirrus sac and excretory bladder; overlapping cæca and lateral folds of uterus.	0·1 × 0·08
C. indicum, n. sp.	20–27 × 4–4·5	0·28 in diameter; 2 : 1.	3 : 2	Club-shaped, reaching anterior wall of intestinal bifurcation.	Behind pharynx.	Extending to the body wall.	From middle of intestinal bifurcation to excretory bladder; overlapping cæca and lateral folds of uterus.	0·1–0·12 × 0·06–0·068

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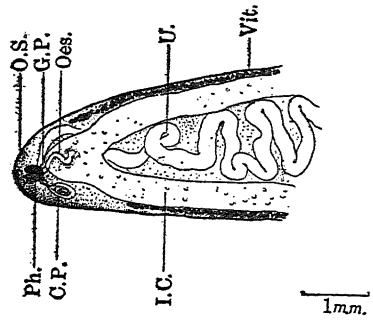


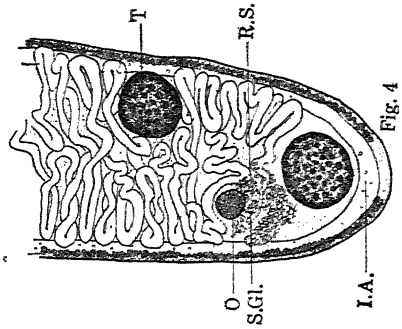
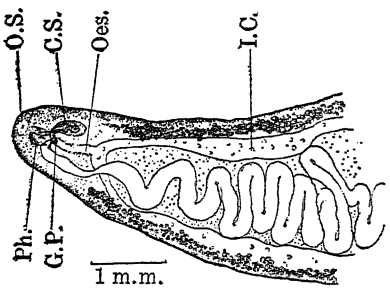


Fig. 4



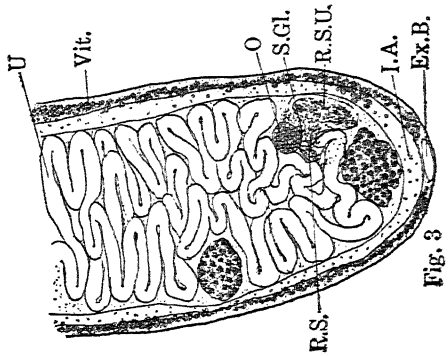
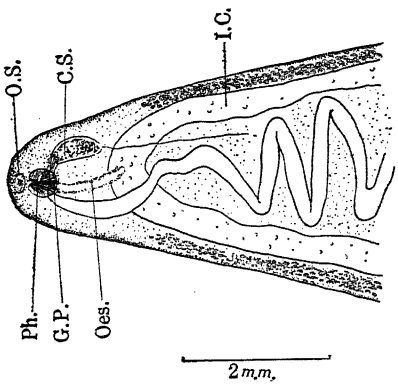


Fig. 3



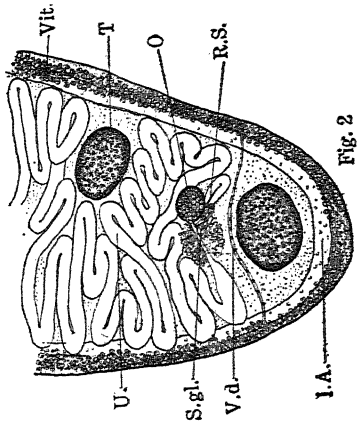
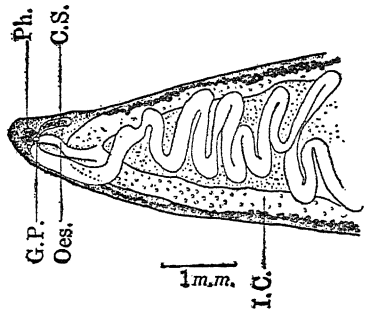


Fig. 2



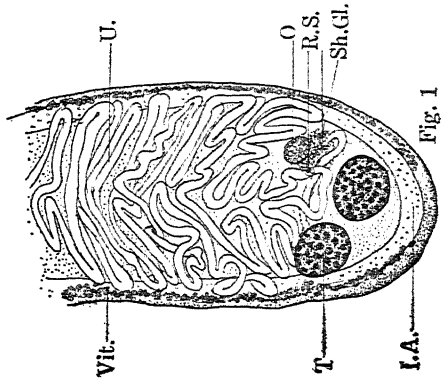
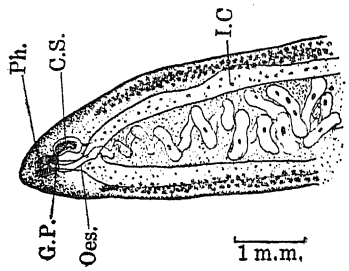


Fig. 1



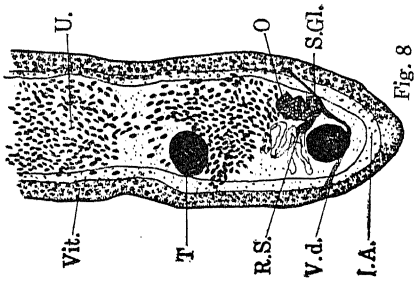
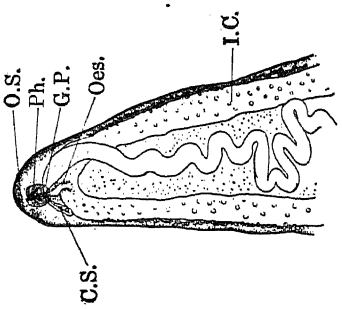


Fig. 8



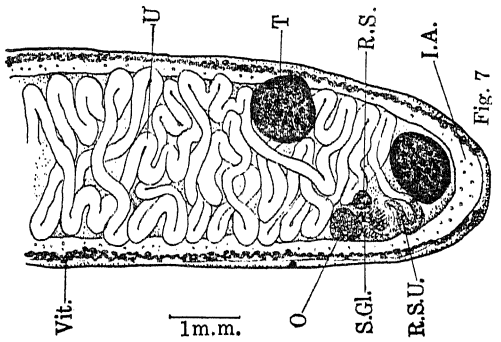
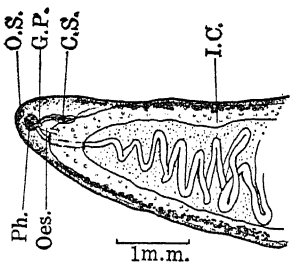


Fig. 7



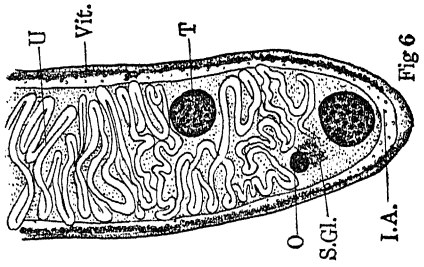
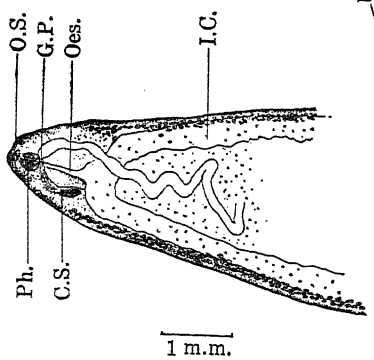


Fig 6



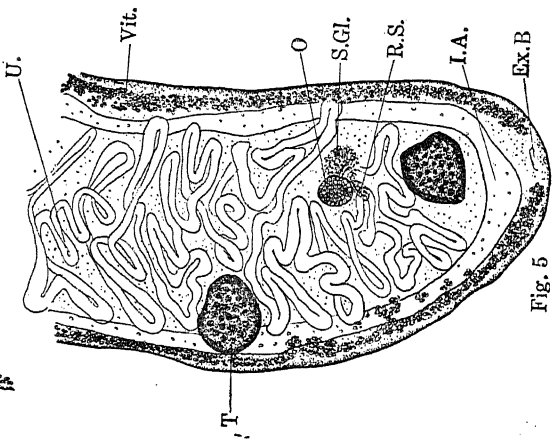


Fig. 5

CONTRIBUTIONS TO THE DIGENETIC TREMATODES OF THE MICROCHIROPTERA OF NORTHERN INDIA

Part 1.—New species of the genus *Pycnoporus* Looss with a note on *Anchitrema* Looss

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Zoology Department, Allahabad University,

Communicated by Dr. H. R. Mehra,

Received December 12, 1934.

Introduction

Hitherto the only contribution to the study of digenetic trematodes from Indian insectivorous bats is that made by Bhalerao (1926) from Burma. This paper, the first of a series dealing with the bat trematodes obtained in this part of the country, contains descriptions of two new species of distomes belonging to the sub-family Lecithodendriinae Looss (family Lecithodendriidae Odhner) and to the genus *Pycnoporus*, representative of which had not been reported previously from this country. The parasites were found in the intestine of *Nycticejus dormeri*, specimens of which were collected in a village fifteen miles north of Allahabad. A short note on the genus *Anchitrema* is appended.

The work has been done under the supervision of Dr. H. R. Mehra to whom I am deeply indebted for his valuable guidance.

Historical account of Pycnoporus

In 1899 Looss established this genus with *Pycnoporus heteroporus* Dujardin (*Dist. heteroporum* Duj. 1845) as the type species and described in the same paper a new species from Egypt under the name *P. acetabulatus*. Dujardin in 1845 had placed his species in the subgenus *Brachycoelium*, but later the species was included in *Lecithodendrium* Lss. Lühe in 1899 had expressed doubts about this inclusion as also that of *Dist. macrolaimus*, a species described by von Linstow in 1894 and also put under *Lecithodendrium*. Braun in 1900 pointed out that Linstow's species

must be placed in the genus *Pycnoporus*. Another new species was described by Looss from Cairo in 1907 under the name *P. inversus*. Ozaki in 1929 gave an account of *P. transversus* along with a key to the species of the genus in which he included Linstow's species as *P. macrolaimus*. Mödlinger in 1930 redescribed *P. heteroporus* Dujardin. Stiles and Nolan in their Key-catalogue cite Linstow's species under *Lecithodendrium*.

Pycnoporus loossii, n. sp.

In the months of August and September 1934 five specimens of *Nycticejus dormeri* were examined by me. Out of these three were found infected with this species: one yielding about twenty specimens, the second only one while the third gave me five specimens. The habitat of the parasites was the small intestine.

The distomes are flat, small in size with the anterior end very mobile and measure 0·63—0·75 mm. in length. In comparatively younger forms they have the same breadth in the posterior half of the body but in older ones the maximum breadth, attained in the post-testicular region in the uterine zone, is 0·28—0·36 mm. The cuticle is spinose and uni-cellular glands are present in the body anterior to the acetabulum. The oral sucker, nearly circular in outline, measures 0·037 mm. in diameter and is subterminal. A spherical prepharynx, measuring 0·01 mm. in diameter, is followed by the pharynx 0·015×0·02 mm. in dimensions. The œsophagus is a long thin tube with the intestinal bifurcation behind the anterior quarter of the body. The intestinal cæca are small elongated sacs ending a little in front of the acetabulum. The latter nearly twice as large as the oral sucker lies nearly at the middle of the body length and measures 0·074 mm. in diameter. In most cases however, it is nearly spherical in outline but is fixed in different shapes on account of its highly contractile nature. The excretory pore lies at the posterior end of the body leading into the V-shape bladder, characteristic of the genus. The genital pore is median and is situated directly in front of the acetabulum.

The testes, more or less ovoid and placed behind the vitellaria slightly oblique to each other, lie laterally near the body wall. The testis of the ovarian side, measuring 0·1—0·125×0·075—0·087 mm. in size, is slightly larger than that on the other side which measures 0·087—0·125×0·0625—0·08 mm. in size. The membranous cirrus-sac, more or less spherical in shape, lies immediately in front of the acetabulum with nearly the whole

of its interior occupied by a much coiled vesicula seminalis. This latter is continued anteriorly into a small pars prostatica which leads into a small ejaculatory duct opening outside at the genital pore. Between the seminal vesicle, the ducts and the wall of the sac are interspersed the prostate gland cells.

The dorsally located ovary is nearly pear-shaped in outline and lies to the left of the acetabulum, measuring 0·08 × 0·063 mm. in size. The oviduct arises from its hinder margin and runs posteriorly to enter the shell-gland complex, situated behind the acetabulum slightly to the left of the median line. In the shell-gland area a nearly rounded receptaculum seminis is discernible, while a little anterior to it the common yolk-reservoir opens. The Laurer's canal is present. The uterus on arising out of the shell-gland complex runs posteriorly between the testes, but behind the latter these descending coils lie mainly to one side of the body, and on reaching the posterior end the uterus turns anteriorly and forms similar coils on the other side of the body behind the testis of that side. Then this ascending limb passing forward in transverse coils in the region of the testes and dorsal to the acetabulum opens to the exterior through the genital pore. The vitellaria are situated laterally to the sides of the shell-gland area in two groups of six to eight follicles each. The group on the ovarian side lies between the ovary and the testis while that on the other is a little ahead in position, and extends anteriorly to the posterior limits of the acetabulum and posteriorly to the anterior limits of the testis of that side. The ripe eggs, elliptical in shape and yellow in colour, measure 0·015—0·0175 × 0·007 mm. in size.

This species resembles *P. heteroporus*, *P. acetabulatus*, and *P. transversus* in having spinose cuticle and the oral sucker being smaller than the acetabulum. It differs from *P. heteroporus* on account of the ratio between the two suckers (acetabulum in Dujardin's species is very powerful and measures 0·32 mm. in diameter while the oral sucker measures 0·065 mm.), the position of the ovary, the slightly oblique position of the testes, the relative position of the vitellaria to the latter, and the size of the eggs (in *P. heteroporus* the length is 0·0819—0·021 and the breadth 0·008 and consequently the eggs are larger in this species). From *P. acetabulatus* it is to be distinguished on account of its obliquely placed testes, the posterior position of the ovary (which is situated somewhat in front of the acetabulum in the former), the posterior position of vitellaria in relation to the acetabulum (in the Egyptian species the follicles are situated to the sides of the acetabulum, the uterus intervening between them and the testes) and the smaller size of the eggs

(which measure 0·023 × 0 01 mm. in size in the species described by Looss). The new species can be differentiated from *P. transversus* on account of the position of the ovary and the position of the vitellaria.

Pycnoporus indicus n. sp.

Five specimens of this species were obtained from the small intestine of three out of eleven bats, *Nycticejus dormeri*, examined by me in the months of March, April, August, September and December, 1934. Two of these infected bats yielded two specimens each while the third yielded only one.

The distomes are thin and somewhat transparent so that a slight pressure of the cover-glass enables the internal anatomy to be elucidated under a low power of a microscope. The body is flat, elongated, somewhat elliptical in shape and measures 1·43—1·59 mm. in length. Both the anterior and the posterior ends are more or less bluntly rounded but the posterior extremity appears to be slightly pointed. The breadth is maximum in the middle third of the body where the gonads are situated and measures 0·42—0·442 mm. The cuticle is smooth and a large number of uni-cellular cutaneous glands is present in the body anterior to the acetabulum. The oral sucker, 0·045 mm. in diameter, is ventrally situated and leads into the pharynx which measures 0·017—0·025 × 0·22—0·03 mm. in size. The œsophagus is long, measuring 0·25 mm. in length, and the intestinal bifurcation takes place in front of one-fourth of the body length from the anterior end. The intestinal cæca are short, wide sacs diverging laterally. The acetabulum, slightly smaller than the oral sucker, measures 0·035 mm. in diameter and is situated in front of one-third of body length from the anterior end. The ratio between the two suckers is 9 : 7. The excretory pore, situated at the posterior extremity of the body, leads into a small median stem which communicates with long spacious cornua of the V-shaped bladder, extending up to the posterior limits of the testes. The genital pore, in front of the acetabulum in the median line, leads into a small genital atrium.

The testes, nearly spherical in shape, are situated obliquely to one another towards the lateral borders one on each side near the equator of the body. The testis on the ovarian side measures 0·156 × 0·121 while that on the other 0·17 × 0·86 mm. in size. The vasa efferentia arising from the anterior end of the testes pass forwards to carry the sperms to the coiled vesicula seminalis which occupies more than two-thirds of

the inside of the pseudo-cirrus sac. The latter is a large spacious structure with its long axis parallel to body length and lies to the side of the acetabulum extending posteriorly much beyond the latter. It measures 0·27 × 0·086 mm. in size. The vesicula seminalis continues anteriorly into the small pars prostatica leading into a well-developed ductus ejaculatorrius, which is eversible as cirrus and opens into the genital atrium by a small pore.

The ovary, oval in shape, lies to the side of the posterior part of the pseudo-cirrus sac, with its anterior limits extending to the level of the hinder border of the acetabulum and measures 0·156 × 0·086 mm. in size. The oviduct arising from its posterior end passes to the median line to enter the shell gland mass which is located centrally near the posterior end of the pseudo-cirrus sac. It is here that the common yolk-reservoir, the receptaculum seminis of 0·05 × 0·037 mm. size, and the Laurer's canal enter the mass. The uterus, after its origin from the mass of the shell gland passes posteriorly between the testes, and behind them it makes a few transverse coils before reaching near the posterior extremity of the body. It then runs forwards as the ascending uterus describing coils, longitudinal and transverse, behind the testes and then passes between them. It then passes forwards in a few coils to open into the genital atrium. The vitellaria are a group of eight to ten follicles lying on each side of the body in front of the testes. Anteriorly they extend to the level of the acetabulum. A vitelline duct from each group passes posteriorly to open into a common reservoir. The ripe eggs are oval in shape and yellow in colour, measuring 0·017—0·02 × 0·008—0·01 mm. in size.

In having the smooth cuticle and the acetabulum smaller than the oral sucker this new species resembles *P. macrolaimus* and *P. inversus* but it differs from them both in the ratio between the two suckers, the size, the extent and structure of the pseudo-cirrus sac-characters which are of sufficient importance to warrant the creation of a new species. Looss did not make a comparison between his species, *P. inversus*, and *P. macrolaimus* with which it is more related than with any other species of the genus. From the short account and the figure given by von Linstow his species appears to differ from *P. inversus* on account of its greater breadth, nearly circular oral sucker, slightly lateral position of the genital pore in front of the acetabulum, more posterior testes and the greater length of the ova.

The diagnosis of the genus *Pycnoporus*, as given by Looss and Stiles and Nolan, is slightly modified as follows:—

Small Lecithodendriinæ; cuticle densely spinose or smooth; ora sucker smaller or larger than acetabulum; pre-pharynx present or absent; pharynx followed by long œsophagus; intestinal cæca short, ending in front of acetabulum. Genital pore close in front of acetabulum. Excretory bladder V-shaped. Testes distinctly behind acetabulum in uterine zone, symmetrical or asymmetrical; pseudo-cirrus sac with a large, coiled vesicula seminalis, pars prostatica and ejaculatory duct, in the neighbourhood of acetabulum. Ovary in the vicinity of acetabulum; vitellaria pre-testicular, entirely post-cæcal to right and left of acetabulum; uterus in descending and ascending coils lying mainly post-testicular, entirely filling the body behind testes; eggs $15-23 \times 7-11\mu$. Parasitic in intestine of insectivorous bats.

Key to the species of Pycnoporus

1. Acetabulum larger than oral sucker.
   Acetabulum very large and powerful ... *P. heteroporus.*
   Acetabulum not so large.
   Ovary post-acetabular ... ... *P. transversus.*
   Ovary pre-acetabular.
   Vitellaria lateral to acetabulum, with uterus intervening between the follicles and testes ... ... *P. acetabulatus.*
   Vitellaria lateral to shell gland area, never extending anteriorly beyond posterior half of acetabulum and lying in front of testes ... ... *P. loossii*, n. sp.
2. Acetabulum smaller than oral sucker.
   Pseudo-cirrus sac lies in front of acetabulum.
   Oral sucker circular and genital pore slightly lateral close in front of acetabulum ... *P. macrolaimus.*
   Oral sucker longer than broad with its opening longitudinally placed and genital pore median just in front of acetabulum ... *P. inversus.*
   Pseudo-cirrus sac extends posteriorly much beyond acetabulum ... ... *P. indicus*, n. sp.

Note on Anchitrema Looss

Nycticejus kuhli and *N. dormeri*, the common insectivorous bats available at Allahabad, are found to harbour in its rectum an interesting

Lecithodendrid worm—*Anchitrema sanguineum*—first discovered by Sonsino in the gut of *Chamæleo vulgaris* and described by him in 1894 as *Distomum sanguineum*. This species was fully described by Looss in 1896 who found it in the intestine of chamaeleons and in the terminal part of the intestine of bat—*Taphozous nudiventris*—in Egypt. Later Looss regarded this species as the type of a new genus, *Anchitrema*, created by him in 1899. Odhner reported the presence of this species in chamaeleons and bats— *Rhinolophus hippocrepis*—from Western Nile. Two of the fifteen bats examined by me from March to September 1934 were each found infected with only one specimen of this species.

Description :—Body elongated, tongue-shaped, with a bluntly rounded anterior end and a pointed posterior end, measuring 3·23—5·15 mm. in length and 1·1 mm. in maximum breadth attained in the region of acetabulum, whitish in colour with intestinal cæca red on account of the blood of the host in them, spinose. Oral sucker subterminal, roughly circular in outline, measuring 0·29—0·41 × 0·32—0·46 mm. followed by spherical pharynx, 0·12 mm. in diameter; œsophagus short; intestinal cæca long sinuous, dorsally situated, ending a little in front of posterior end. Acetabulum smaller than oral sucker, 0·27—0·32 × 0·37 mm. in size, located near union of first and second third of body length, ratio between the suckers being 5 : 4. A large number of uni-cellular glands in the body anterior to testes and acetabulum. Genital pore median, in front of acetabulum. Excretory pore terminal and bladder Y-shaped seen in sections. Testes oval, symmetrical, ventral and lateral to intestinal cæca with anterior ends nearly in level with posterior limits of acetabulum, and somewhat equal in size—the right one measuring 0·34—0·58 × 0·25 while the left one 0·34—0·65 × 0·22—0·35 mm.; pseudo-cirrus-sac just in front of acetabulum with a highly coiled vesicula seminalis, opening outside through pars prostatica and ejaculatory duct; prostate gland cells well-developed. Ovary immediately post-testicular, median, dorsally situated, spherical and 0·24—0·27 mm. in diameter; shell-gland mass just behind ovary, also median; Laurer's canal dilated and coiled: receptaculum seminis absent; uterus in descending and ascending transverse coils, occupying the entire post-testicular space, lying ventral to intestinal cæca and extending laterally to vitellaria; metraterm well-developed, coiled, beginning in front of ovary, lying medianly between testes, dorsal and lateral to acetabulum; vitellaria well-developed, post-testicular, lateral to cæca near bodywall, follicles on right extending more posteriorly with 0·54—0·78 mm. space free from posterior end while on left 0·68—0·9 mm.; eggs numerous, oval, measuring 22 × 12μ.

The apparent differences between these specimens and those described by Looss relate to the posterior extent of vetellaria and egg measurements, otherwise there is a close resemblance, and I think they belong to the same species—*A. sanguineum*.

Anchitrema was placed under Dicrocoeliinæ by Pratt in 1902 but Odhner recognised the genus as belonging to the sub-family Lecithodendriinæ. Poche follows the same course as regards the systematic position of the genus. Führmann has included this genus under Pleurogenetinæ.

The two important characters which make the position of the genus in the Lecithodendriinæ rather questionable are the Y-shaped excretory bladder and the intestinal cæca extending post-acetabular to near the posterior end. In this respect *Anchitrema* resembles *Eumagacetes* Looss (*Megacetes* Lss.). But against this there is the general agreement in the arrangement of the genitalia, the terminal portion of the male duct the length of the ova and the host being insectivorous animal. Further in some Lecithodendriinæ the excretory bladder is not typically V-shaped but has a tendency to become Y-shaped with a very small median stem. It is, however, considered proper to include this genus for the present in Lecithodendriinæ.

In his descriptions of trematode parasites, Tubangui in 1928 records a new species of *Platynosomum*, *P. philipinoromum*, found parasitic in the Philippine bat, *Scotophilus temnicki*. His identification of the parasite appears to me to be erroneous. I think the trematode belongs to *Anchitrema* because of the armed cuticle, Y-shaped excretory bladder, preacetabular median genital pore (which is situated at œsophageal bifurcation in *Platynosomum*), extracæcal testes (which is shown in his diagram but not mentioned in his description) and the habitat (generally the Dicrocoeliinæ are parasitic in liver and gall-bladder). Tubangui describes the cirrus-sac as pear-shaped in his species but does not say whether it is muscular or membranous (the latter being the case in *Anchitrema* while former in *Platynosomum*).

Explanation of the Plate

Fig. 1, Dorsal view of a mounted specimen of *Pycnoporus loossii*, n. sp.

Fig. 2, Dorsal view of a mounted specimen of *P. indicus*, n. sp.

Fig. 3, Dorsal view of a mounted specimen of *Anchitrema sanguineum*.

Key to lettering

acet., acetabulum; c., cirrus; c.u., uterine convolutions; d.ej., ductus ejaculatorius; g.o., genital opening; i.c., intestinal cæcum; l.t., left testis; met., metraterm; oes., œsophagus; o.s., oral sucker; ov., ovary; p.g., prostate gland cells; p.p., pars prostatica; ph., pharynx; ps. s., pseudo-cirrus-sac; r.s., receptaculum seminis; r.t., right testis; sh. g., shell gland complex; v. sem., vesicula seminalis; vit., vitellaria; y r., yolk reservoir.

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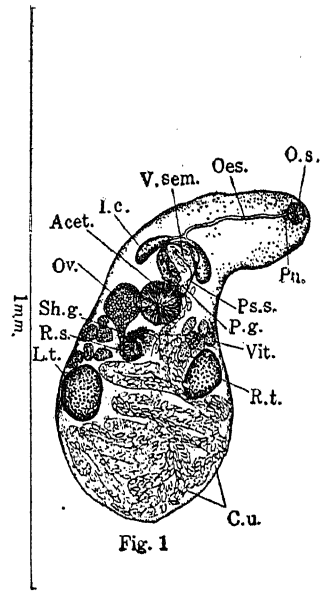

Fig. 1

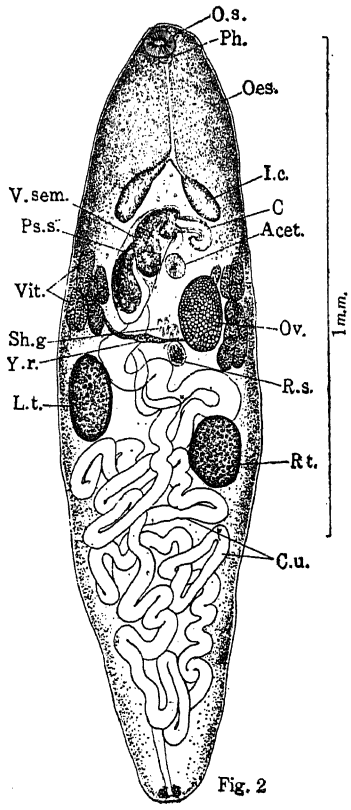

Fig. 2

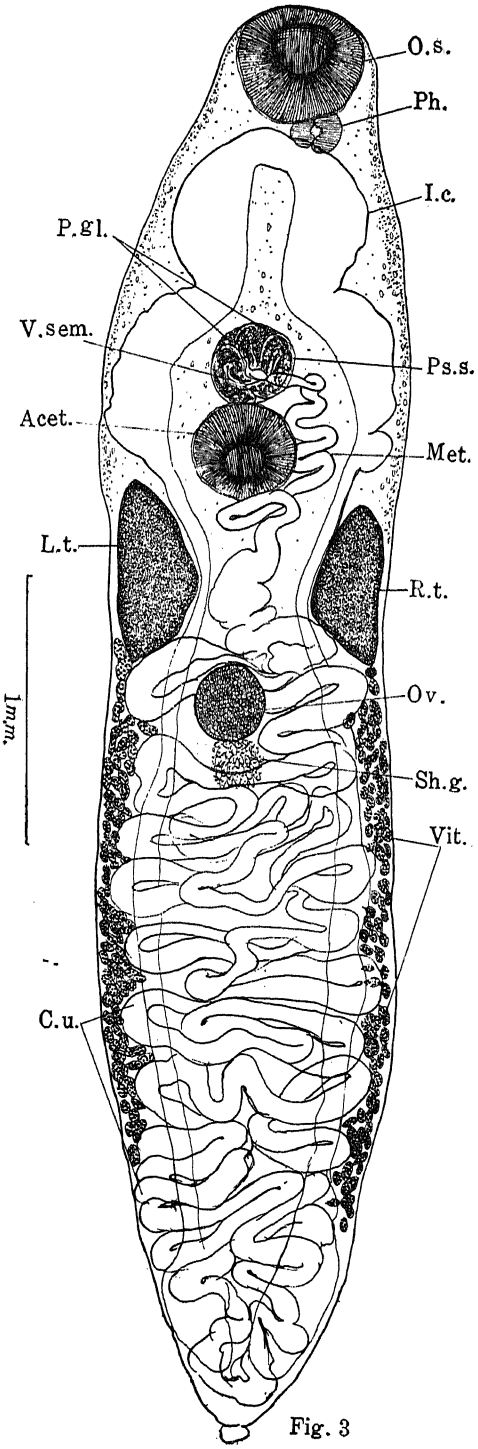

Fig. 3

NEW HEMIURIDS (TREMATODA) FROM INDIAN FRESH-WATER FISHES

Part 1—"New Distomes of the Genus Lecithaster Luhe, 1901, from Clupea ilisha."

By Har Dayal Srivastava

Zoology Department, University of Allahabad

Communicated by Dr. H. R. Mehra

Received October 29, 1934.

One of the common fresh-water fish in the market in Northern India is *Clupea ilisha*, known as Helsa in vernacular. The fish is found in large numbers in the local rivers for about eight months in the year. It becomes rare towards the end of summer and almost totally disappears during the rainy season. It is found infected with a large number of interesting helminths in different seasons. In winter it is found infected with several interesting trematodes belonging to the sub-families Sterrhurinæ, Lecithasterinæ, Dinurinæ and Fellodistominæ and cysts of cestode larvæ. In summer the Trematode infection clears off and instead the fish is parasitised by Acanthocephala and Linguatulids. In this paper I give an account of two new species of *Lecithaster*.

The genus was established by Luhe in 1901 for *Dist. bothryophoron* Olsson, 1868, which Odhner in 1905 showed to be actually *Dist. gibbosus* Rud., 1802. Subsequently the following species have been described under the genus, *Lecithaster*: *L. confusus* Odhner, 1905, *L. stellatus* and *L. galeatus* Looss, 1907, *L. anisotrema* MacCallum, 1921, *L. lindburgi* Layman, 1930, and *L. salmonis* Yamaguti, 1934. The account of the two species described by Looss in 1907, *i.e.*, *L. stellatus* and *L. galeatus*, is very meagre and is insufficient for correct identification. The two species, however, cannot be retained under *Lecithaster* on account of the character of the ovary which, according to Looss, is unlobed. Yamaguti in 1934 described a parasite from the intestine of a Japanese Fish—*Halichoeres*

poecilopterus under the name *L. stellatus* Looss, which differs from Looss' specimen in the character of the ovary which is 4-lobed and the shorter length of the vesicula seminalis which does not extend behind the acetabulum. The Japanese species obviously is a very different parasite from *L. stellatus*. *L. anisotrema* MacCallum has rightly been considered by Manter, 1931, a synonym of *Brachadena pyriformis* Linton, 1910. Yamaguti in 1934 has assigned *L. lindburgi* to Tubulovesicula Yamaguti, 1934.

Lecithaster indicus, n. sp.

This species represents a common parasite in the intestine of *Clupea ilisha* at Allahabad. The rate of infection in winter is nearly 100% when practically every fish is found harbouring the parasite. The number of parasites in a single host varies from 8 to 20. The distomes live firmly attached to the wall of the intestine and do not come out as soon as the gut is cut open in salt solution. In the living condition they are light brown in colour and lack any marked power of contraction and expansion. When alive they attach themselves by means of their powerful ventral sucker and move their ends in a leech-like manner. In salt solution they can live for 10—12 hours.

The body is muscular, fusiform or spindle-shaped with a nearly uniform diameter, except at the ends which are bluntly pointed. The body is smooth and entirely devoid of spines or cuticular denticulations. Sexually mature worms in balsam mounts measure 0·95—1·7 * in length and 0·24 – 0·43 in maximum breadth which lies across the region of the acetabulum. Unicellular cutaneous gland cells are present in fairly large numbers in the preacetabular region behind which they occur only sparsely.

The suckers are well developed and muscular. The sub-terminal oral sucker is slightly broader than long measuring 0·065 – 0·083 × 0·083—0·11 in size. The acetabulum, 0·16 – 0·17 in diameter, is situated a little behind the intestinal bifurcation at about the middle of anterior half of body. The oral sucker opens posteriorly into a very small prepharynx visible in sections only. The pharynx is muscular and oval measuring 0·06 – 0·07 × 0·048—0·063 in size. A short but definite œsophagus of 0·04—0·063 length is present. The cæca are long and sinuous with crenated margins extending posteriorly to a little distance in front of the hinder end. They are equal in length. The oral sucker, prepharynx, pharynx, œso-

* All measurements are in mm.

phagus and a small length, 0·07—0·1, of the cæca are all lined internally with cuticle.

The testes, two in number, are small, spherical or transversely oval structures with markedly indented outline, situated symmetrically or asymmetrically, one on each side, close behind the acetabulum in the second quarter of body. The right testis, of 0·07—0·09 × 0·07—0·12 size, is slightly smaller than the left which measures 0·9—0·11 × 0·07—0·1 in size. The vesicula seminalis is an undivided bulb-shaped structure of 0·14—0·16 × 0·06—0·12 size lying in the intercæcal space with its posterior two-thirds length extending behind the acetabulum upto the hinder margin of testes. The pars prostatica is a fairly long, 0·16—0·19, tube lined internally by a row of rectangular cells with prominent nuclei, and is surrounded by a large number of flask-shaped prostate gland cells, which, as in other hemiurids, lie free in the parenchyma. Anteriorly it opens into the posterior tip of the sinus sac and after receiving the metraterm from the right side continues into a tubular genital sinus or ductus hermaphroditicus of 0·09—0·1 length. The latter is surrounded by a pyriform sinus sac measuring 0·09—0·1 × 0·04—0·05 in size, *i.e.*, half the length of pars prostatica. The genital sinus opens on the ventral surface at the level of intestinal bifurcation or just in front of it. It is usually median but sometimes is shifted slightly to one side.

The ovary of 0·23—0·33 × 0·1—0·22 size consists of four elongated bulb-shaped lobes all connected together in the centre and measuring 0·1—0·16 × 0·05—0·07 in size. It is situated in the posterior three quarters of the body partly overlapping the cæca. A well developed, bulb-shaped receptaculum seminis of 0·12—0·17 × 0·06—0·09 size is situated in the intercæcal space just in front of the ovary. Laurer's canal is present.

The vitellaria, 0·21—0·24 × 0·12—0·13 in size, consists of seven finger-shaped lobes with saccular distal ends, varying from 0·12—0·17 × 0·03—0·44 in size and are all connected together in the centre. It is situated in the median line close behind the ovary overlapping the cæca. The shell gland complex lies between the ovary and vitellaria.

The uterus is arranged in irregular longitudinal coils extending from the acetabulum to a little distance in front of the posterior end. Terminally the uterus is continued into a short, 0·03 × 0·008, metraterm which enters the sinus sac to form the genital sinus. The male and female ducts do not unite outside the sinus sac. The eggs are numerous, small and operculate, measuring 0·015—0·02 × 0·007—0·01 in size.

The excretory bladder is of the usual hemiurid type, *i.e.*, Y-shaped with the cornua uniting dorsal to the pharynx.

In its relationship the species stands nearest to *L. salmonis* Yamaguti, 1934. But it differs from the latter in the length of the cæca, extent of vesicula seminalis, shape of testes and of ovarian and vitelline lobes, position of genital pore and the much smaller size of eggs.

Host—*Clupea ilisha*.

Habitat—Intestine.

Locality—Allahabad (Rivers—Ganges and Jumna.)

Lecithaster extralobus, n. sp.

The parasite has a smooth, muscular, spindle-shaped body, tapering at both ends. Under slight pressure it measures 1·44 in length and 0·47 in greatest breadth across the vesicula seminalis. Suckers are spherical and muscular. The subterminal oral sucker, of 0·08 diameter, is smaller than the acetabulum which measures 0·16 across and is situated at the junction of the first and second quarters of body. The ratio between oral and ventral suckers is 1 : 2. Prepharynx and œsophagus are absent. Pharynx highly muscular and globular, 0·06 in size. Cæca first run at right angles to pharynx and then turn downwards extending in a sinuous course to the hinder end. Oral sucker, pharynx and anterior horizontal portion of cæca are all lined internally with cuticle. The cæca are of unequal length; the left being larger extending to posterior tip while the right ends a little in front of the latter.

Testes, two in number, are more or less ovoid in shape and lie asymmetrically, one on each side, behind the acetabulum. The left testis, 0·4 in size, is more cephalad, lying just behind acetabulum while the right of 0·6 size is situated some distance behind ventral sucker in close contact with ovary. Vesicula seminalis is fairly large in size, measuring 0·17 × 0·09, and is slightly constricted in the middle, situated in the median line obliquely behind acetabulum, extending posteriorly upto anterior margin of right testis and receptaculum seminis. Pars prostatica is a straight tube of 0·21 × 0·03 size, lined internally with flat cells with prominent nuclei and is surrounded all along its length with well developed prostate gland cells which are flask-shaped with long flowing necks. Anteriorly it enters the sinus sac at its posterior tip to continue as the genital sinus after receiving metraterm from the right. The sinus sac measures 0·09 × 0·04 in size. The genital pore is ventral, median, just behind intestinal bifurcation.

Ovary, 0·23 × 0·31 in size, consists of five huge lobes which are all connected in the centre and lies just behind the anterior half of body in

the median line partly overlapping cæca. Receptaculum seminis is a large elongated sac-shaped structure, 0·17×0·08 in size, situated slightly to the left side between vesicula seminalis and ovary. Vitellaria, 0·19×0·29 in size, consist of eight finger-like lobes, as in *Hysterolecitha microrchis* Yamaguti, 1934, with swollen ends lying immediately posterior to ovary. The lobes are all connected anteriorly in the median line and are disposed in a characteristic manner in two groups of four each, one group lying on either side of median line. An irregularly lobed shell gland mass, 0·04×0·05, lies between ovary and vitellaria. Uterus is well developed and stuffed with numerous golden yellow eggs, extending in longitudinal coils from vesicula seminalis to a short distance in front of posterior end. The eggs are oval and thin-shelled, measuring 0·015×0·01 in size. The excretory bladder is as in *L. indicus*.

Besides differences in the size of the various organs this species differs from all the species of the genus in the absence of œsophagus, unequal length of cæca, and in having the ovary divided into five instead of four and the vitellaria into eight instead of seven lobes.

Host—*Clupea ilisha*.

Habitat—Stomach.

Locality—Allahabad (Rivers—Ganges and Jumna).

I am deeply indebted to Dr. H. R. Mehra under whom this work was carried out for his valuable help and guidance. Thanks are due to Dr. D. R. Bhattacharya for providing me laboratory facilities in the Department. I am grateful to the Trustees of the Lady Tata Memorial Trust, Bombay, for the grant of a research scholarship for investigations in Helminthology.

Explanation of Figures

Fig. 1. Ventral view of *Lecithaster indicus*.
Fig. 2. „ „ „ *L. extralobus*.

Lettering

Act. Acetabulum.
G. p. Genital pore.
G. s. Genital sinus.
I. c. Intestinal cæcum.
M. Metraterm.
O. s. Oral sucker.
Oes. Œsophagus.
Ov. Ovary.

P. gl. Prostate glands.
P. p. Pars prostatica.
Ph. Pharynx.
R. sem. Receptaculum seminis.
S. gl. Shell gland.
S. s. Sinus sac.
T. Testis.
Ut. Uterus.
V. sem. Vesicula seminalis.
Vit. Vitellaria.

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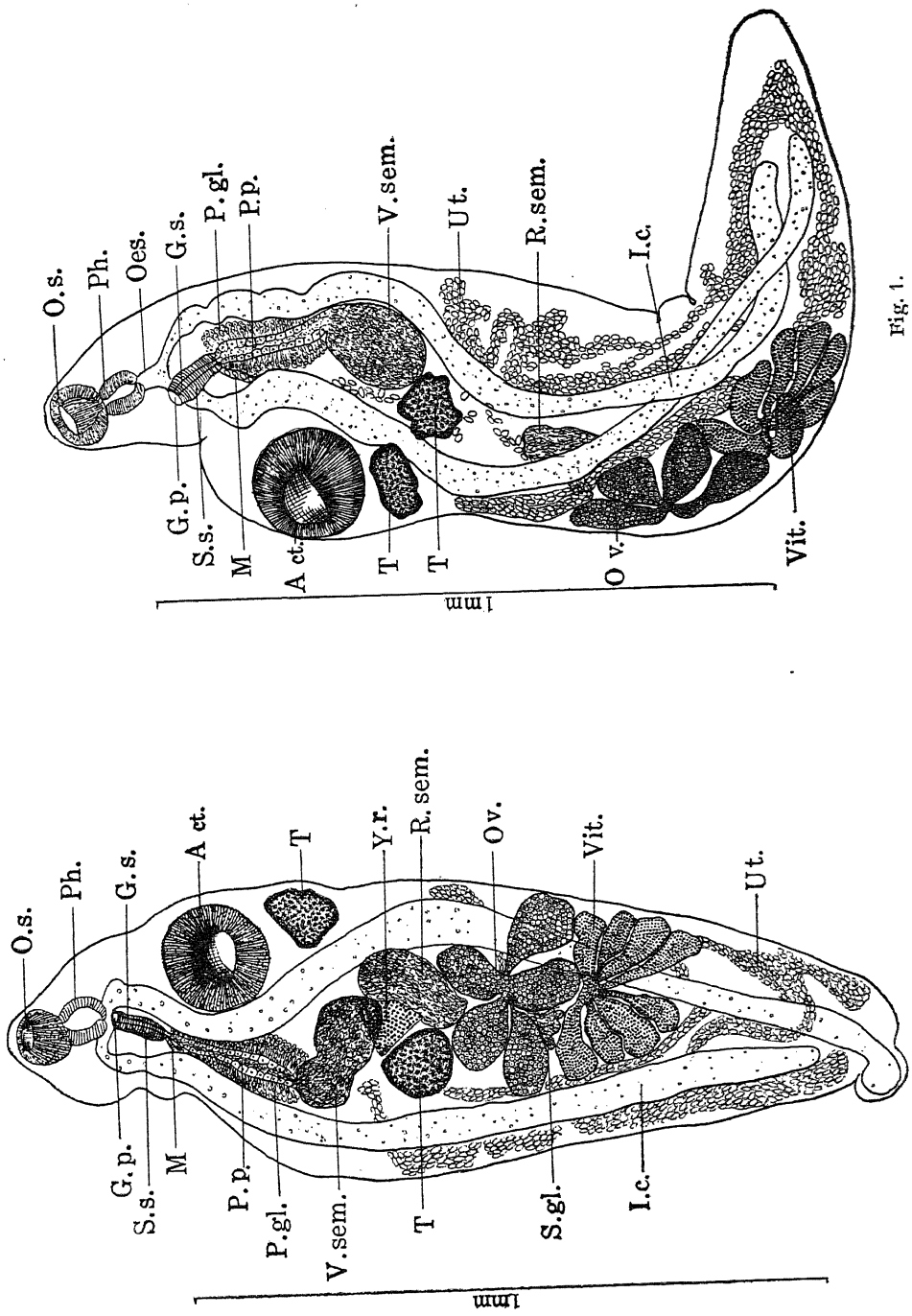
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Fig. 1.

SOME POLYPORACEÆ FROM THE CENTRAL PROVINCES

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Communicated by Prof. J. H. Mitter

Received March 9, 1935

A large collection of Polyporaceæ was made in 1930 during the rainy season from Jubbulpore, Khandwa, Burhanpur and other places in the Central Provinces. My search for these fungi extended over only a brief period, and it is therefore certain that the collection does not include all the Polyporaceæ likely to occur at these stations during the monsoon. It must also be noted that the collection was more or less confined to these towns and their near vicinities. The fact that a fairly large collection of all the genera of Polyporaceæ could be made in a short time from so limited an area would go to show the abundance of the Polyporaceæ at these places. Almost all the forms collected have been investigated and their structure studied in detail. I am here describing only five of the collected species which deserve a special mention.

(1) *Polyporus indicus* Mass.

Locality and Habitat—collected from Jubbulpore in August, 1930, growing singly on a log of *Acacia arabica*.

Pileus	...	Stipitate, fan-shaped, thinning out towards the margin, coriaceous when fresh, stiffens on drying.
Margin	...	Thin, reflexed and sterile.
Upper Surface	...	Rough with wrinkles, concentrically zonate, almost Sulphine yellow in colour, margin of somewhat deeper tinge.
Hymenial Surface	...	Saccardo's umber in colour, pores very minute, angular, and regular. Pore tubes about 1—1·5 c.m. long, quite distinct from the context which is Sanford's brown.
Spores	...	Globose, Sanford's brown, about 4·2—5·6 mic. in diameter.

(2) *Polyporus agariceus* Berk—

Locality and Habitat—Collected from Khandwa in August, 1930. Growing singly on a wounded branch of *Ficus religiosa*.

Pileus	...	Stipitate, fan-shaped, 2 × 1·2 c.m., partly soft and coriaceous.
Margin	...	Very thin, fertile, wavy and partly reflexed.
Upper Surface	...	Smooth to touch, cobalt-red in colour.
Hymenial Surface	...	Almost of the same colour as the upper surface, pores large, elongated, roughly hexagonal, pore tubes extremely short.
Spores	...	Subhyaline, very small, somewhat sub-globose, 1·4—2·5 mic. in diameter.

(3) *Polyporus cuticularis*, (Bull.) Pat.

Locality and Habitat—collected from Jubbulpore in August, 1930, growing in clusters on a log of wood, and also from Burhanpur in August, 1930.

Pileus	...	Dimidiate, arc-shaped, about 4—12 c.m. long, some of them were resupinate, forming scattered patches of varying sizes on the log, and $\frac{1}{4}$—1 c.m. thick, hard and brittle in dry condition.
Margin	...	Thick, broad, wavy and fertile.
Upper Surface	...	Smooth, colour varies in tone, red, scarlet red, and some old specimens of Burnt-Sienna. Very thin cuticle, and inconspicuously zonate.

Prof. Bose collected Polyporus Cuticularis in 1918 from Darjeeling. The upper surface of his specimen was hairy. Dr. J. H. Mitter and R. N. Tandon collected the same species from Naini Tal in 1928 which was also hairy on upper surface. In my specimen hairs are lacking. Development of hairs in Darjeeling and Naini Tal specimens is probably due to severe cold or frost.

Hymenial Surface	...	Almost of the same colour as the upper surface, Pores circular, pore-mouths torn, pore tubes about $\frac{1}{4}$—$\frac{1}{2}$ c. m. long.
Context	...	Pale-auburn, fibrous, fairly thin and shining.

Basidia ... ... Shrivelled up, and almost hyaline.

Spores ... ... Some roundish, some almost oval, 5—7·5 mic. in diameter.

(4) Poria Calcea (Fr.) Bres=Poria vulgaris var. Calceator.
Locality and Habitat—collected from Jubbulpore in August, 1930. Growing as scattered patches only on the bark of a log of wood.

Pileus ... ... Resupinate, scattered patches of varying size and thickness, 4—8 m.m. thick, coriaceous in fresh state, on drying it becomes somewhat hard and brittle, upper surface smooth and glossy.

Hymenial Surface ... White-brown, pores very minute, unequal in size, somewhat angular and not uniform. Pore tubes short.

Basidia and spores ... Not found.

(5) Fomes pallidus—Petch.

Locality and Habitat—collected from Jubbulpore in August, 1930 from the trunk of a tree.

Pileus ... ... Odouriferous, smooth, hard, resupinate with bracket-forming tendency. Some of them entirely resupinate, some with bracket formations, varying in size from 1·5—4·5 c.m.

Margin ... ... In bracket forms it is broad, thick and sterile; in resupinate ones it is thin, wavy and sterile, and mars-yellow in colour.

Context ... ... Whitish-buff, about ·5—1·5 m.m. thick.

Hymenial Surface ... Maize-yellow, pores angular and elongated, dissepiments of the pores thick, pore tubes vary in depth from 5—8 m.m. and concolorous with the context.

Spores ... ... Not found.

I am indebted to Prof. J. H. Mitter for his suggestion of the problem and also to Prof. S. R. Bose, who had very kindly identified the collection.

Explanation of Plate I

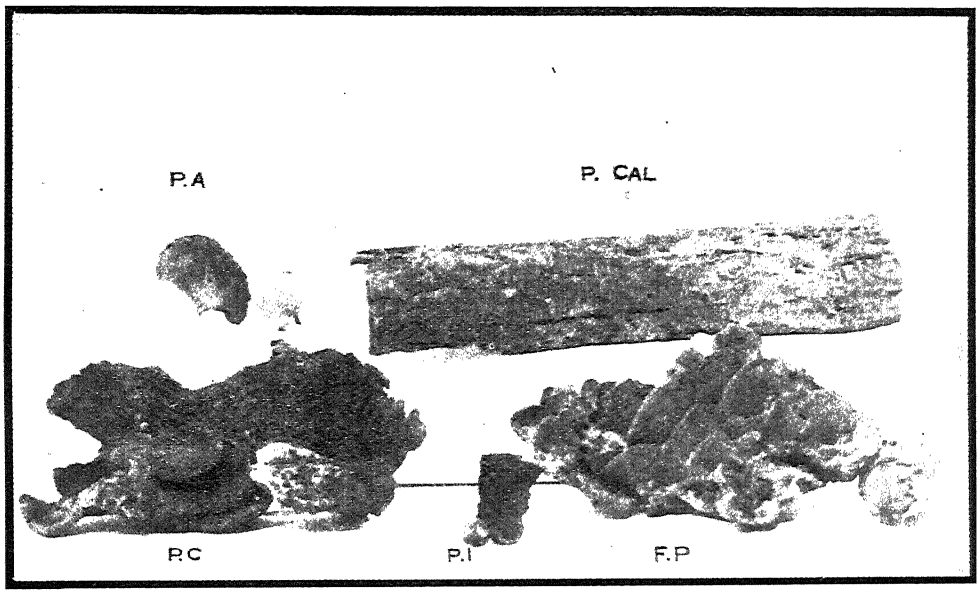
P. A. ... ... Polyporus agariceous, Berk, showing the upper and the hymenial surfaces of the sporophore.

P. Cal. ... .. Poria calcea (Fr.). Bres,=Poria vulgaris Var. calceator, showing resupinate patches.

P. C. ... ... Polyporus cuticularis, (Bull.) Pat.

P. I. ... ... Polyporus indicus, Mass.

F. P. .. ... Fomes pallidus, Petch.



DETERMINING SIZES OF MANGUM TERRACE OUTLETS

By A. T. Mosher,

Agricultural Institute, Allahabad

Communicated by Mr. Mason Vaugh

Received January 19, 1935

The usual method of designing small open channels for agricultural purposes where extreme accuracy is not necessary is: (1) to find the quantity of water to be handled in cubic feet per second as determined by the area to be drained and the rate of run-off; and (2) by trial and error, assuming different ditch dimensions, to experiment until a combination of dimensions is found which will handle the necessary amount of water per second and at the same time give the water a velocity which is not excessive for the type of soil in which the channel is to be located.

The first of these operations is outlined in the simple formula:

$$Q = \frac{AR}{86{,}400}$$

in which Q is the discharge in cubic feet per second, A is the area to be drained (in square feet), and R is the depth of water (in feet) to be removed from the soil in twenty-four hours.

Example:—What will be the discharge in cubic feet per second necessary to remove 6 inches of water from 5 acres of land in 24 hours?

$A = (5)\ (43{,}560) = 217{,}800$ square feet

$R = \frac{1}{2}$ or 0·5 feet

$$\text{then } Q = \frac{(217800)\ (0{\cdot}5)}{86{,}400} = 1{\cdot}26 \text{ cubic feet per second.}$$

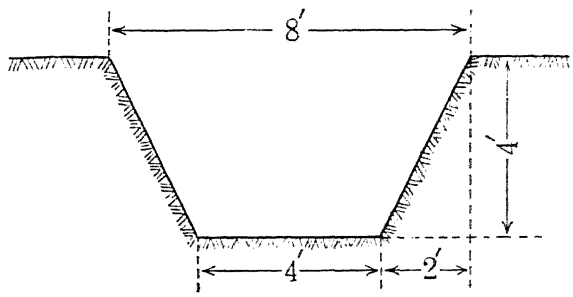
The second operation is performed with the help of *Elliott's Open-Ditch Formula*, which is

$$V = \sqrt{\left(\frac{a}{p}\right)\left(\frac{3}{2}h\right)}$$

in which V is the mean velocity in feet per second, a is the area of the

cross-section of the ditch in square feet, p is the wetted perimeter of the channel in feet, and h is the fall along the channel in feet per mile.

Example:—What will be the mean velocity in an open ditch 8 feet wide and 4 feet deep with 2 : 1 side slopes and a fall of 20 feet per mile?



$$a = \left(\frac{8+4}{2}\right)(4) = 24 \text{ square feet}$$

$$p = 4 + 2\sqrt{4^2+2^2} = 12{\cdot}94 \text{ feet}$$

$$h = 20$$

$$V = \sqrt{\left(\frac{24}{12\,94}\right)\left(\frac{3}{2}\,20\right)}$$

$$= 7{\cdot}45 \text{ feet per second.}$$

Thus by assuming widths and depths, one can experiment until he finds a combination of width and depth, which, with the fall available, will give the necessary discharge without exceeding the allowable velocity in the soil type concerned.

The difficulty with this procedure is that, while it is simpler than the use of the more exact Chezy-Kutter formula, it still presents too many complications for the average Intermediate or even B.Sc. graduate in agriculture to apply by himself without more expert help. If the use of the Mangum terrace is to spread into general use as a major method of soil erosion control, some method of deciding on outlet channel dimensions must be devised which will be very simple in application, yet dependable in results.

Such a method may be developed by the following procedure:

(1) *Standardize the type of ditch surface.*

For most Indian conditions a *sodded* channel offers the most advantages. It is productive; the grass may be cut to be used as feed. It is economical, being cheap to construct and requiring none of the materials necessary for wooden

or masonry channels. It resists erosion, having a much more stable surface than any type of soil without vegetation and thus allowing greater velocities without harm to the channel.

(2) *Standardize the ratio of channel width to channel depth.*

From the standpoint of cost of excavation, a ditch which is twice as wide as it is deep is most economical. Furthermore, when used with 2:1 side slopes, it gives the maximum discharge with the minimum velocity of any common channel shape.

(3) *Standardize the slope along the ditch.*

If these three standardizations are made, it becomes possible to develop a formula and from it to compile a single table in which anyone can locate the required outlet dimensions if he knows (1) the area to be drained, and (2) the maximum run-off probable in any period of 24 hours.

Every Intermediate or B.Sc. graduate in agriculture should be able to compute areas and the probable run-off in 24 hours is so definitely indicated by geographical location that each student can be shown in the classroom what the maximum probable run-off in his section of the country may be.

Derivation of the Formula.—The formula used in making this table is a very simple derivation from the two equations already given.

(1) $$Q = \frac{AR}{86{,}400}$$

and (2) $$V = \sqrt{\left(\frac{a}{p}\right)\left(\frac{3}{2}h\right)}$$

and upon the third formula that:

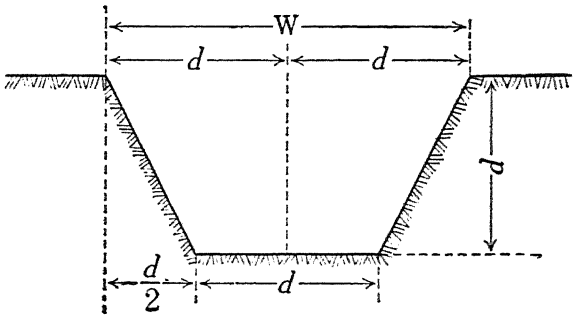
(3) $$Q = aV$$

where Q is the discharge in cubic feet per second, a is the cross-sectional area of the channel in square feet, and V is the mean velocity in feet per second.

Standardizing the width of the channel as twice the depth makes it possible to find the cross-sectional area (a) and the wetted perimeter (p) of the channel in terms of the width (w).

$$a = \left\{\frac{w + \left(w - 2\frac{d}{2}\right)}{2}\right\}(d)$$

$$= \frac{w + \frac{2w-2d}{2}}{2} (d)$$



Standardized Relationship

$$= \frac{2w-d}{2} (d)$$

$$= \frac{2w-\frac{w}{2}}{2} \left(\frac{w}{2}\right)$$

$$= \left(\frac{3w}{4}\right) \left(\frac{w}{2}\right)$$

$$= \frac{3w^2}{8}$$

(I) $a = .375\ w^2$

Also $p = \left(w-2\frac{d}{2}\right) + 2\sqrt{d^2 + \left(\frac{d}{2}\right)^2}$

$$= (w-d) + 2\sqrt{\frac{5d^2}{4}}$$

$$= w-d+2\ (1.118\ d)$$

$$= w+1.236\ d$$

$$= w+0.618\ w$$

(II) $p = 1.618\ w$

It is obvious that h (fall in feet per mile) is equal to $52.8s$ where s is the % slope (fall in feet in 100 feet) inasmuch as there are 5280 feet in one mile.

These values may now be substituted in the Elliott Formula :

$$V = \sqrt{\left(\frac{a}{p}\right)\left(\frac{3}{2}h\right)}$$

with the following results :

$$V=\sqrt{\left(\frac{\cdot375\ w^2}{1\cdot618w}\right)\left(\frac{3}{2}52\cdot8s\right)}$$

$$=\sqrt{(\cdot2317\ w)\ (79\cdot2s)}$$

$$=\sqrt{18\cdot35\ ws}$$

(III) $\qquad V^2=18\cdot35\ ws.$

but since $\quad Q=aV$ (Formula 3 ; page 394),

$$V=\frac{Q}{a}$$

and $\quad V^2=\frac{Q^2}{a^2}$

Now $a=\cdot375\ w^2$, (see I), and $V^2=18\cdot35\ ws$, (see III) ;

Therefore, $\quad 18\cdot35\ ws=\frac{Q^2}{(\cdot375\ w^2)^2}$

$$18\cdot35\ ws=\frac{Q^2}{\cdot1406\ w^4}$$

Then, $\quad 2\cdot580\ w^5s=Q^2$

$$w^5=\frac{Q^2}{2\cdot58\ s}$$

(IV) And, $\qquad w=\sqrt[5]{\frac{Q^2}{2\cdot58\ s}}$

We now have a formula by means of which a table can be made showing *for a particular value of* s the width of channel necessary to give a certain discharge.

Since the accepted engineering practice is to design a channel to run ·8 full at full capacity, the factor 5/4 should be inserted to care for this. The formula then assumes its final form :

(V) $\qquad w=\frac{5}{4}\sqrt[5]{\frac{Q^2}{2\cdot58\ s}}$

Limiting Velocities :

It is impossible to keep the *slope* of the channel and *the relation of width to depth* constant without varying the velocity of flow. For this reason it is necessary to determine the point at which the slope must be

reduced in order not to exceed the velocity at which erosion of the channel itself would occur.

No data on the allowable velocity in *sodded* channels is known to this writer. In volume 2 of his book "Irrigation Practice and Engineering," Etchverry gives the following as maximum values of mean velocities safe against erosion:

Material	*Mean Velocity* (in feet per second)
Very light pure sand, quicksand character	0·75 to 1·00
Very light, loose sand	1·00 to 1·50
Coarse sand or light sandy soil	1·50 to 2·00
Average sandy soil	2·00 to 2·50
Sandy loam	2·50 to 2·75
Average loam, alluvial soil, volcanic ash soil	2·75 to 3·00
Firm loam, clay loam	3·00 to 3·75
Stiff clay soil, ordinary gravel soil	4·00 to 5·00
Coarse gravel, cobbles, shingles	5·00 to 6·00
Conglomerates, cemented gravel, soft slate, tough hardpan, soft sedimentary rock	6·00 to 8·00
Hard rock	10·00 to 15·00
Concrete	15·00 to 20·00

In view of this data, it has been decided to use a limiting value of 7·5 feet per second in these tables. This may seem to be too high. It has been chosen with regard to the following considerations:

(1) That a terrace outlet is used only a very small part of each year.

(2) That the periods when the channel will be filled *to capacity* will come perhaps once in two or three years and will then last only a few hours.

(3) That the maximum flow will occur at that time of year when the grass is growing rapidly so there should be practically complete sod covering on the soil.

Using, then, a value of 7·5 feet per second as a maximum velocity we arrive at the allowable width of channel as follows:

In developing formula III, page 396, we have the relationship:

$$V = \sqrt{18{\cdot}35\, ws}$$

By assigning values to s, and replacing V with 7·5 feet per second, we can find the desired maximum channel width allowable.

Because of ease of calculation by the student or graduate constructing a channel and of adequacy to most conditions, slopes of 1% and 0.5% have been decided upon for this table. For the 1% slope then, and the maximum velocity of 7.5 feet per second, the limiting value of w is found.

$$V = \sqrt{18.35\, sw}$$

$$7.5 = \sqrt{18.35\, w} \quad (1)$$

$$7.5 = 4.28\sqrt{w}$$

$$w = \left(\frac{7.5}{4.28}\right)^2$$

$w = 3.06$ feet, which is the maximum width of a channel when $w = 2d$; $s = 1\%$; side slopes are 2:1; surface of the channel is sodded; and the maximum mean velocity is 7.5 feet per second.

Similarly, for a 0.5% slope:

$$V = \sqrt{18.35\, w\, s}$$

$$7.5 = \sqrt{18.35\, w\, (0.5)}$$

$$7.5 = \sqrt{9.175\, w}$$

$$7.5 = 3.03\sqrt{w}$$

$$w = \left(\frac{7.5}{3.03}\right)^2$$

$w = 6.13$ feet, which is the maximum width of a channel when $w = 2d$; $s = 0.5\%$; side slopes are 2:1; surface of the channel is sodded; and the maximum mean velocity is 7.5 feet per second.

Since, however, the channel widths shown in the table are to be 5/4 the width and depth necessary for capacity operation, these limiting widths will be shown as 5/4 of the above values and will become:

For 1% slopes . . . . . 3.83 feet
For 0.5% slopes . . . . . 7.66 feet

Compilation of Table.

With the foregoing data we may now form the table desired. Table I shows the value of Q, or the necessary discharge in cubic feet per second, for different areas and to handle different maximum rates of

run-off. Table II gives w, the necessary width of channel for these same areas and maximum rates of run-off.

The conditions represented by the blank spaces at the upper left-hand corner on Table II are those in which less than 1 cubic foot of water needs to be handled and which would therefore demand only a very small ditch. Under such conditions it is probably unnecessary to establish a 1% slope for the outlet but a sodded strip 4 feet wide and 9 inches lower in the center than along the two sides and following the slope of the field will probably be sufficient.

As noted in Table II, the central portion of the table between the two heavy dividing lines pertains to channels with a slope of 1%; while the small section below the second heavy line and in the lower right-hand corner of the table pertains to channels with a 0·5% grade.

Table I

VALUES OF Q

Inches of Maximum Run-off in 24 Hours

		1	4	8	12	16	20
	1	·042	·168	·336	·504	·672	·840
	2	·084	·336	·672	1·008	1·344	1·680
	4	·168	·672	1·344	2·016	2·688	3·360
	6	·252	1·008	2·016	3·024	4·032	5·040
	8	·336	1·344	2·688	4·032	5·376	6·720
	10	·420	1·680	3 360	5·040	6 720	8·400
	12	·504	2·016	4·032	6·048	8·064	10·080
	14	·588	2·352	4·704	7·056	9·408	11·760
	16	·672	2·688	5·376	8 064	10·752	13·440
Area	18	·756	3·024	6·048	9·072	12·096	15·120
	20	·840	3·360	6·720	10·080	13·440	16·800
in	22	·924	3·696	7·392	11·088	14·784	18·480
	24	1·008	4·032	8·064	12·096	16·128	20·160
Acres	26	1·092	4 368	8·736	13·104	17·472	21·840
	28	1·176	4·704	9·408	14·112	18·816	23·520
	30	1·260	5·040	10·080	15·120	20·160	25·200
	35	1·470	5·880	11·760	17·640	23·520	29·400
	40	1·680	6·720	13·440	20·160	26·880	33·600
	45	1·890	7·560	15·120	22·680	30·240	37·800
	50	2·100	8·400	16·800	25·200	33·600	42·000
	55	2·310	9·240	18·480	27·720	36·960	46·200
	60	2·520	10·080	20·160	30·240	40·320	50·400

Table II

VALUES OF *W*

Maximum Run-off in Inches in 24 Hours

Area in Acres	1	4	8	12	16	20	
1							
2	Regular channel unnecessary			1·04	1·16	1·27	
4			1·16	1·37	1·54	1·68	
6		1·04	1·37	1·61	1·81	1·98	
8	See p. 399	1·16	1·54	1·81	2·03	2·22	
10		1·27	1·68	1·98	2·22	2·42	
12		1·37	1·81	2·12	2·38	2·60	
14		1·46	1·92	2·26	2·54	2·79	Slope
16		1·54	2·03	2·38	2·67	2·92	is
18		1·61	2·12	2·50	2·80	3·06	1%
20		1·68	2·22	2·60	2·92	3·20	
22		1·74	2·30	2·69	3·03	3·33	
24	1·04	1·81	2·38	2·80	3·15	3·44	
26	1·07	1·88	2·46	2·89	3·24	3·55	
28	1·10	1·92	2·54	2·98	3·34	3·65	
30	1·13	1·98	2·60	3·06	3·44	3·76	
35	1·20	2·10	2·79	3·25	3·65	4·58	
40	1·27	2·22	2·92	3·44	4·43	4·85	Slope
45	1·33	2·32	3·06	3·60	4·65	5·08	is
50	1·39	2·42	3·20	3·76	4·85	5·30	0·5%
55	1·44	2·51	3·33	4·44	5·06	5·50	
60	1·50	2·60	3·44	4·65	5·21	5·70	

NOTE.—For practical use there is no advantage in having this table carried further than one decimal place as tenths of feet are as close as most will come to accurate construction.

SUMMARY

We now have a simple yet dependable guide to sizes for open channel terrace outlets. By using the column in Table II which serves the maximum run-off in 24 hours probable in the locality in which the channel is to be constructed, one may, by simply knowing the area to be served, read directly the width and slope which the channel should have. It has been decided that the depth shall be one-half of the width; that the side slopes shall be 2:1 and that the surface of the channel shall be sodded. All of the necessary data have been provided.

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